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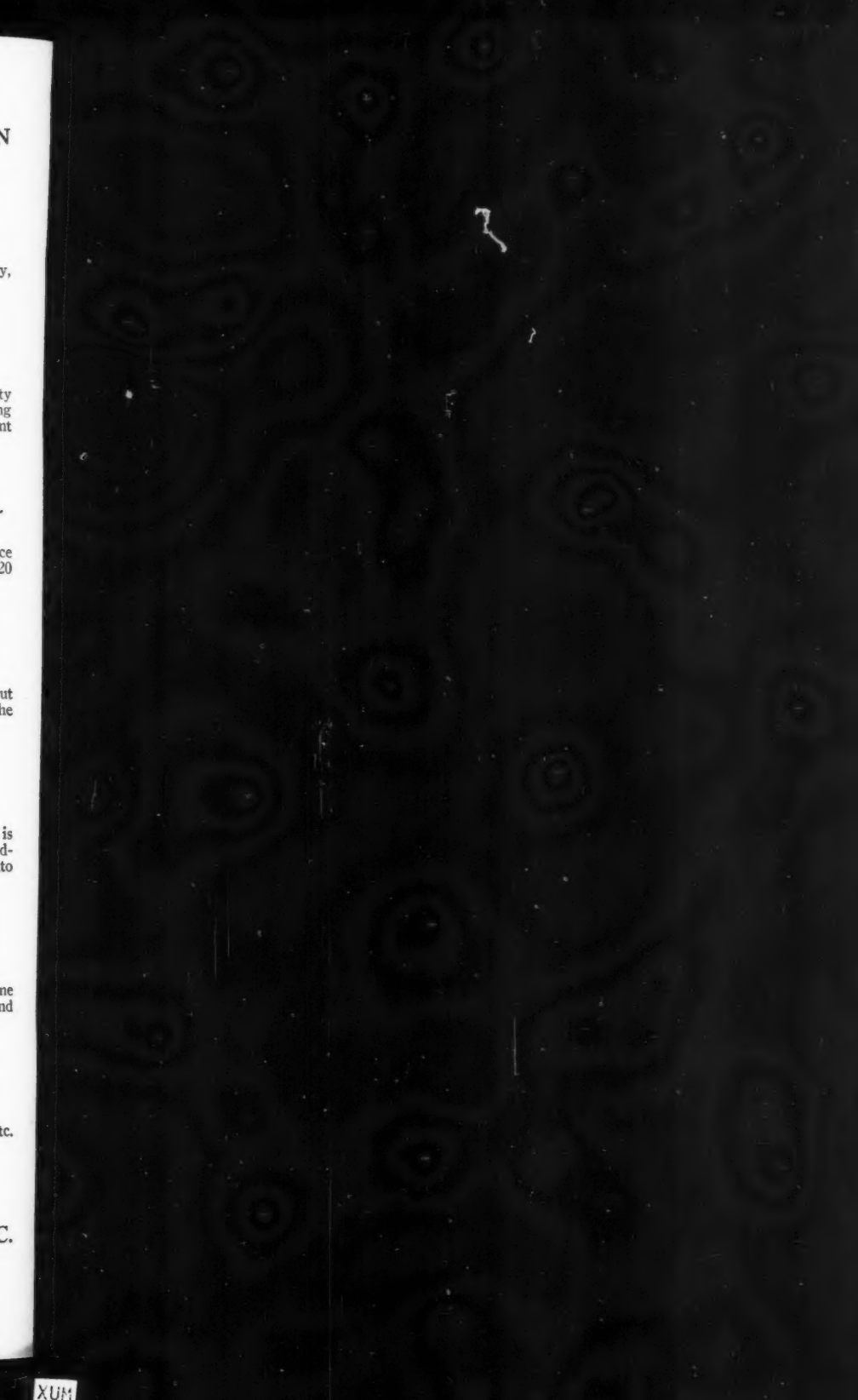

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# CONDITIONED INHIBITION AND CONDITIONED EXCITATION IN TRANSFER OF DISCRIMINATION [1]

BY FRANCES K. GRAHAM

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Although no experimental work has been explicitly carried out on this problem, it is generally assumed that practice in one discrimination will favor the learning of a second discrimination. This transfer effect might be thought of in terms of training a general discrimination ability, of adaptation to experimental procedure, of establishing a general attitude of caution, or it might be analyzed in terms of the component elements of the two learning situations. In other words, once transfer effect is demonstrated, is it possible to discover the mechanism of transfer?

In the present experiment, two discrimination situations were set up in such a way that there could be transfer from one to the other and this transfer could be mediated by a conditioned inhibitor or conditioned excitor. The results are analyzed to determine whether or not transfer of discrimination occurs, and to determine whether or not this transfer can be called a transfer of conditioned inhibition or conditioned excitation.

Conditioned inhibition is defined by the peculiar experimental arrangement in which a differentiation is established between a positive conditioned stimulus and a negative, non-reinforced combination consisting of the positive stimulus plus an added stimulus. Similarly, conditioned excitation, suggested by Hull (**6**), is defined by an arrangement in which the differentiation is between a negative, non-reinforced stimulus and a reinforced combination consisting of the negative stimulus plus an added stimulus. The additional stimulus

[1] This experiment was a dissertation presented for the degree of Doctor of Philosophy in Yale University, 1942. The writer wishes to express her appreciation to Professor Clark L. Hull who directed this investigation and in whose laboratory the work was carried out and to Dr. Judson S. Brown, Dr. Carl I. Hovland and Dr. Donald G. Marquis for valuable aid in preparing the report.

is called, respectively, the conditioned inhibitor or the conditioned excitor, and the cue stimulus in the present experiment corresponds to this.

If conditioned inhibition and conditioned excitation are restricted in meaning to a particular experimental arrangement of stimuli, they are concepts of relatively little importance, for, although given a special name, they can be considered simply as forms of discrimination learning. Pavlov, however, has claimed that the conditioned inhibitor exerts an inhibitory effect on responses with which it has never previously been associated when it is presented with the stimuli to those responses (**12**). This will be referred to as *transfer* of conditioned inhibition. The conditioned excitor may be assumed to have an analogous exciting effect on other responses. The significance of this statement, if proven true, would be quite widespread. It would mean that, by virtue of establishing the particular discrimination called conditioned inhibition or excitation, the discriminated stimulus (the conditioned inhibitor or excitor) would henceforth have a generalized inhibiting or exciting effect when presented with any other stimulus. The implications of this for a psychology of prestige, social behavior, etc. have been pointed out by Hull (**6**).

While no work has been done on conditioned excitation, Pavlov has demonstrated the transfer of conditioned inhibition by two experiments. In the first experiment, three conditioned reflexes, all based on the same unconditioned stimulus, food in mouth, were established independently to three different conditioned stimuli by the usual method of repeatedly pairing a conditioned stimulus and an unconditioned stimulus. An additional stimulus was then given occasionally with one of the conditioned stimuli, and whenever the combination was applied, the unconditioned stimulus was omitted. Eventually, the conditioned response failed to occur in the presence of the combination. Following this, the additional stimulus was presented with a second conditioned stimulus whose response, salivation, was thereby reduced from 17 to 2 drops. This procedure was repeated with another additional stimulus and the same results noted. The second experiment was substantially the same, except that heterogeneous reflexes, i.e., reflexes based on different unconditioned stimuli, were used. The different unconditioned stimuli were food in mouth and acid placed in the mouth. The response was measured in both cases by the amount of salivation. No experimental evidence showing the effect of the conditioned inhibitor on unconditioned reflexes was reported, but Pavlov states that "the inhibitory effect may extend even to the unconditioned reflexes themselves" (**12**).

There are several other studies of the establishment of conditioned inhibition, differing in technique and subjects used, but the condi-

tioned inhibitors are not tested with other responses to give evidence of transfer effect (**15, 16, 17**). As mentioned previously, it is this transfer effect which gives the concept of conditioned inhibition its general significance. The question arises as to whether or not Pavlov's experiments have demonstrated such an effect satisfactorily or whether his results can be explained by factors which are independent of the peculiar experimental arrangement called conditioned inhibition. It appears possible that two factors, namely, external inhibition and secondary extinction, might be responsible for the transfer of inhibition effect.

First, since the conditioned inhibitor has never been presented with the test conditioned stimulus before, it may simply act as an external inhibitor. The effect of an external inhibitor, that is, any novel stimulus which is presented with a positive conditioned stimulus, is to inhibit the response to that conditioned stimulus. Though Pavlov recognized this possibility and attempted to control for it, the method of doing so is not stated. A paper by Lindberg, a student in Pavlov's laboratory, suggests that it was done by repeatedly applying the additional stimulus alone until it ceased to evoke the orienting reaction and "became extinguished as an external inhibitory agent" (**8**). This method is not altogether satisfactory since isolated application causes the stimulus to become not indifferent but actually to acquire inhibitory effect (**12**). Since Pavlov's procedure is not entirely clear, the possibility that the 'inhibitory property' of the conditioned inhibitor is due to its action as an external inhibitor cannot be ruled out.

Secondly, the effect of the conditioned inhibitor might be due to secondary extinction (or generalization of extinction). Secondary extinction, as defined by Hilgard and Marquis, is "the extinction of other conditioned responses which results when any one conditioned response undergoes extinction" (**2**). Thus, the extinction of the compound that is part of the process of establishing conditioned inhibition may be generalized to another reflex, and, in this way, account for the apparent effect of the conditioned inhibitor when presented with the stimulus to the second reflex. Skinner has pointed out in this connection that the occurrence of secondary extinction would depend upon the 'inductive interrelations,' the interactions, of the reflexes used (**18**). In Pavlov's experiments, there is reason to believe that the reflexes used were not independent. They involved the same effectors, the response being salivation even though in response to different unconditioned stimuli. And even if there were no response interaction, Pavlov himself claims that secondary extinction may involve not only homogeneous reflexes, but also those which are based upon a different unconditioned reflex (**12**).

These factors are eliminated in the present experiment, since transfer of conditioned inhibition is tested in the learning of a discrimination. Thus, while the additional stimulus might have an externally inhibiting effect on its first presentation, its continued presentation in the discrimination would cause it to lose whatever effect of this sort it might have had. Likewise, secondary extinction could not aid in the learning of a discrimination, since it would affect both the stimuli to responding and the stimuli to not-responding equally. A third interpretation of Pavlov's results will be discussed later in connection with the results of this study.

## General Procedure

The procedure involved training animals in a discrimination which permitted the establishment of conditioned inhibition or conditioned excitation and then transferring them to a different discrimination. Twenty animals were trained on conditioned inhibition and 20 on conditioned excitation. The additional stimulus was a buzzer, which accompanied non-reinforced trials in the conditioned inhibition groups and reinforced trials in the conditioned excitation groups.

Conditioned inhibition was established by training 10 of the 20 animals to run down an alley to a food-box when a shutter was raised but to inhibit running when the buzzer was sounded previous to raising the shutter. The other 10 animals were trained to press a bar for food when the bar was inserted into an experimental box and to inhibit bar-pressing when the buzzer accompanied its insertion. To test transfer of conditioned inhibition, the group that was trained in the alley was then transferred to the bar-pressing situation and retrained. The reverse procedure was carried out with the animals first trained to press the bar. Since the group using a particular apparatus first served as a control for the group transferred to that apparatus, each group of 10 served as a control for the other 10. The group learning the alley first was designated as the initial inhibition alley group. When shifted to the experimental box, this same group was called the transfer inhibition box group.

TABLE I

Listing of the Discriminations Learned by Each of the Experimental Groups

| | | | |
|---|---|---|---|
| Cond. inhibitor | Group 1 | 1<br>raising shutter → reinf. (+)<br>*Buzzer* + raising shutter<br>→ no reinf. (−) | 2<br>inserting bar → reinf. (+)<br>*Buzzer* + inserting bar<br>→ no reinf. (−) |
| Cond. inhibitor | Group 2 | 3<br>inserting bar → reinf. (+)<br>*Buzzer* + inserting bar<br>→ no reinf. (−) | 4<br>raising shutter → reinf. (+)<br>*Buzzer* + raising shutter<br>→ no reinf. (−) |
| Cond. excitor | Group 3 | 5<br>*Buzzer* + raising shutter<br>→ reinf. (+)<br>raising shutter → no reinf. (−) | 6<br>*Buzzer* + inserting bar<br>→ reinf. (+)<br>inserting bar → no reinf. (−) |
| Cond. excitor | Group 4 | 7<br>*Buzzer* + inserting bar<br>→ reinf. (+)<br>inserting bar → no reinf. (−) | 8<br>*Buzzer* + raising shutter<br>→ reinf. (+)<br>raising shutter → no reinf. (−) |

The groups used in the training listed on the left were subsequently trained in the manner listed on the right. The groups in diagonal boxes were compared. Thus, box 1 served as a control for box 4; box 3, as a control for box 2.

Conditioned excitation was established by training 10 animals to run down the alley when the shutter was raised and the buzzer sounding and to inhibit running when the shutter was raised but the buzzer was absent. Similarly, 10 other animals were taught in the experimental box to press a bar when the bar was inserted and the buzzer was sounded and to inhibit bar-pressing when the buzzer was not sounding. Transfer of conditioned excitation was tested by shifting groups to the apparatus with which they had had no previous experience. The group learning the alley first was called the initial excitation alley group and, when transferred to the box, was called the transfer excitation box group. A listing of these procedures may be found in Table I.

## Subjects and Apparatus

The *Ss* for this experiment were 45 male albino rats, Brooklyn strain, averaging about 90–100 days old and ranging from 190 to 225 gm. in weight. They had had no previous training of any kind. During the course of the experiment, five rats were discarded: two for failure to learn, one because of illness, one because of an extreme inhibitory response to the buzzer, and one because of a disturbed response to the buzzer similar to that described by Maier (9). All were discarded in the first stage of training, prior to their use in an experimental group.

Two types of apparatus were employed, a modification of the Skinner-Youtz box, and a short, straight alley. The modification of the Skinner-Youtz box has been described in detail by Williams (19) and Ellson (1). It consisted of an animal compartment, measuring one foot on a side, which was partially soundproofed and vacuum-ventilated. The rear wall was formed by a metal panel through which a horizontal bar could be introduced by means of a hand-operated lever outside the box. Pressure on this bar released a small pellet of food into a cup below the bar. On non-reinforced trials the food release mechanism was disconnected. The compartment was lighted by means of a feeble glow from a 7.5 watt bulb in series with a 1000 ohm resistance. The bulb rested on the observation window in the top of the box. A toggle switch was placed in such a position that it was tripped by the lever inserting the bar. In this way, the resistance was shunted out, increasing the intensity of the light. Utilizing a change suggested by Perin (14), a small, glass-topped box, $6 \times 5 \times 12$ inches, whose rear wall was formed by the metal panel, was placed inside the large cubic box. This smaller box, used as the animal compartment, was designed to limit the rats' activity and thus reduce somewhat the variability in scores. Water was always present in the box.

The alley was 6 feet long, 6 inches wide and 6 inches high, constructed of wood and covered by a coarse mesh screen. The rat was placed first in the entrance box, $6 \times 6 \times 6$ inches, which was separated from the alley by a shutter and a cardboard barrier which acted as a valve, permitting movement in only one direction. The shutter was raised by the experimenter, the valve opening when the rat pressed against it. At the other end of the alley, a food box, of the same dimensions as the entrance box, was separated from the alley by a second valve. This apparatus was one section of a 40-foot alley employed by Hull in an earlier study (5).

Four signal markers, mounted on a constant-speed waxed paper polygraph, recorded (1) the entrance and retraction of the horizontal bar, (2) downward pressure on the bar, (3) movement of the shutter in the alley, and (4) movement of the valve opening into the food box. Single coil buzzers were mounted on both the Skinner box and the alley, but their activation was not recorded on the polygraph.

## Specific Procedure

Each animal was put through a period of preliminary feeding, habituation, and training on the response and discrimination habits in both apparatuses. Response training corresponded to the setting up of the positive conditioned response by Pavlov. The responses of running or bar-pressing were learned during this stage and only subsequently was discrimination training introduced. By using both apparatuses at the same time, it was possible to run two animals in a group simultaneously.

1. *Feeding.*—The treatment of the animals before training followed closely the procedures used by Williams and Ellson (19, 1). In order to establish a feeding and activity rhythm, the animals were fed Purina chow one hour a day for three days at the time at which training was to take place.

2. *Habituation.*—The four days of habituation were begun by placing the rats in the experimental apparatuses for two days, food being given for one hour each day. An habituation alley,

similar to the experimental alley except for omission of the shutter, valves, and entrance and food boxes, was used in the case of the alley groups. On the third day, the rats were permitted to obtain 20 pellets, one at a time. In the Skinner box, the experimenter operated the food mechanism without introducing the experimental bar. This served to habituate the animals to the click of the apparatus which accompanied release of the pellets. For the other group, the experimental alley was used, with the valves and shutter left open. Food was placed in the food box, the animals being started from the middle of the alley on each of the 20 trials. Five additional grams of food were given in the living cages on these days. The same plan was followed on the fourth day, except that alley groups were started from the entrance box instead of the middle of the alley.

3. *Pre-discrimination Response Training.*—Following habituation, two days of response training were given. This consisted of 25 reinforced trials, with an interval of 30 ± 15 sec. between trials. In the case of the conditioned excitor groups, the buzzer was sounded for three sec. before the beginning of the trial and was continued until a response had been made. The buzzer was not used in the conditioned inhibitor groups. This procedure kept the conditions under which reinforcement occurred constant for response and discrimination training. Five additional grams of food were given in the living cages.

The procedure in the Skinner box during response training was to insert the bar, which, when depressed by the rat, released a pellet into the food container. The bar was withdrawn immediately. Introduction of the bar in both conditioned excitor and inhibitor groups was accompanied by an increase in intensity of the light. This accessory signal was thought to be desirable for cases in which the rat was faced so that it was unable to see the entrance of the bar. Until this time the rats had had no experience with the bar, and in some cases it was found necessary to smear a small amount of wet mash on it, in order to elicit the desired response. Occasionally, three or four pellets were obtained 'accidentally' while the rat was attempting to remove the moist food. Apparently, in these cases, the pellets in the tray were not observed and a long period intervened before they were secured and eaten. The first reinforcement, therefore, was not counted until the rat had pressed the bar and immediately found the pellet. This practice has been found by Perin (13) to give reliable results.

The alley procedure was similar. The rat was placed in the entrance box. After the shutter had been raised, a pellet of food could be obtained from the food box by running through the closed valves. On the first five trials of the first day, both valves were held slightly open by a wooden block. On the sixth and seventh trials, only the second valve was left open, and on subsequent trials both valves were completely closed. Preliminary experimentation showed that this partial closing of the valves eliminated fear reactions which occurred and persisted in many rats on the initial presentation of the closed valve.

4. *Discrimination Training.*—Following response learning, training was begun on the discrimination habit. Thirty trials, with an interval of 30 ± 15 sec. between them, were given daily. Ten of these were reinforced with pellets and 20 were not reinforced. The distribution of reinforced and non-reinforced trials was partially randomized by shuffling a pack of 20 black and 10 red cards. The randomizing was restricted by reinforcing the first trial and by permitting no more than four non-reinforced or more than one reinforced trial to occur in sequence. In the conditioned excitation groups, when a trial was to be reinforced, the additional stimulus, the buzzer, was sounded for three sec. prior to insertion of the bar or raising of the shutter and continued until a response occurred.[2] There was no additional stimulus when a trial was not to be reinforced. The reverse presentation was used with the conditioned inhibition groups. The buzzer was not given when the trial was to be reinforced. It was sounded only when the trial was not to be reinforced and was continued until the trial had ended. After completion of the 30 trials, the rat, as usual, was fed in its cage, the amount of food being increased to eight gm. to provide a sustenance diet during the long period of experimentation.

On the first day of this training, a trial was terminated immediately following a response, whether the trial was reinforced or not reinforced. On subsequent days, however, the trial was terminated immediately following a response only when it was reinforced. When the trial was not reinforced, it was continued for 60 sec., no matter how many responses were made in that period. This 60-sec. wait was necessary to avoid reinforcing responses by terminating trials as

[2] The practice of beginning the buzzer three sec. before the trial started and continuing it until the trial was terminated was found to facilitate the establishment of discrimination. Pavlov had suggested such a procedure as favorable to establishment of the conditioned inhibition (12).

soon as the responses occurred, but it had to be omitted on the first day because extinction frequently occurred during the wait.

In a few cases, responses failed to occur on reinforced trials even after three min. A second reinforced trial was then given. The latency of the first trial only was counted. In rare cases, when no response occurred on this second trial, the rat was removed to its cage for 30 min., after which training was resumed. Only one rat failed to respond when treated in this way, and it was therefore discarded.

Training on the discrimination habit was continued until 28 of the 30 trials were without error on any one day. On reinforced trials, a response was counted as an error if it had a latency of over 10 sec.; that is, if a response did not occur until more than 10 sec. after the trial was begun. On non-reinforced trials, any response occurring within the 60-sec. waiting period was counted as an error.

5. *Transfer Training.*—When the criterion of 28 errorless trials had been reached, a rat was transferred to the apparatus on which it had not been trained and the above procedure, except for the preliminary feeding, was repeated. Training was completed when the rat had learned the discrimination habit in both the alley and the box.

Training procedure may be summarized briefly as follows:

1. Three days feeding for one hour a day.
2. Four days habituation: two days feeding and living in apparatus, two days on each of which 20 pellets were given.
3. Two days pre-discrimination response training: 25 reinforced trials on each day. The buzzer was sounded in the conditioned excitation group.
4. Discrimination training to a criterion of two errors in 30 trials. Thirty trials a day were given, 20 of these non-reinforced and 10 reinforced. Buzzer accompanied reinforced trials in the excitation groups and non-reinforced trials in the inhibition groups.
5. Transfer to the other apparatus and repetition of the procedure outlined in steps 2, 3, and 4.

## Results

### 1. *Transfer of Discrimination*

In order to demonstrate transfer, it is necessary that there be a reliable difference between the discrimination learning of the initial and transfer groups, whether conditioned inhibitor or excitor. Two

TABLE II

Measures of Discrimination Learning

Mean and standard deviations are given for each group. Transfer is indicated by smaller means in the transfer groups.

| Group | Days | | Errors | |
|---|---|---|---|---|
| | Initial | Transfer | Initial | Transfer |
| Inhibitor Alley | 15.5±4.9 | 7.3±1.7 | 199.4± 13.2 | 86.1±31.0 |
| Inhibitor Box | 15.8±7.9 | 7.9±4.2 | 195.0±133.1 | 95.7±73.5 |
| Excitor Alley | 20.1±4.7 | 3.6±1.6 | 271.6± 71.9 | 32.2±22.3 |
| Excitor Box | 18.2±8.8 | 8.8±4.0 | 220.2±149.8 | 106.8±39.3 |

measures of learning, time and errors, were used. The number of days to reach the established criterion of discrimination was taken as the time measure of learning, and the total number of errors made in reaching the criterion was taken as the error measure. The measures are not independent, of course.

Table II gives the means and standard deviations of the time and error scores for each initial and transfer group. The distributions were not markedly skewed. It may be observed that in every case the means of the transfer groups are smaller than those of the initial groups. This difference is in accord with an expectation of transfer.

TABLE III

RELIABILITIES OF DIFFERENCES IN LEARNING BETWEEN INITIAL AND TRANSFER GROUPS

The upper figure in each cell is the *t*-value of the mean difference between initial and transfer groups. The lower figures give the probabilities that these differences could have risen by chance.

| Group | Days | Errors |
|---|---|---|
| Inhibitor | 4.7 | 4.3 |
| Alley | <.001 | <.001 |
| Inhibitor | 2.6 | 2.0 |
| Box | .009 | .030 |
| Excitor | 10.0 | 9.5 |
| Alley | <.001 | <.001 |
| Excitor | 2.9 | 2.2 |
| Box | .005 | .021 |

The reliability of the mean differences may be seen from Table III which gives the *t*-values and the probabilities that the differences obtained are due to chance rather than to the experimental variables. If the .01 probability level is taken as the criterion of significance, six of the eight differences are significant.[3] Transfer is thus demonstrated.

Statistical treatment also showed that days to learn and errors made in learning were not significantly affected, either by the particular apparatus used, or by the position of the buzzer as a conditioned inhibitor or excitor.

A difference between initial and transfer groups might also be found by comparing the average latencies per reinforced and nonreinforced trial in the two groups. Table IV shows, however, that there is no consistent difference. An increase in latency was present only in alley transfer groups on the first day, and occurred irregularly in six of the eight groups on the 50 percent learning day and in four of the eight groups on the last day.

[3] The *t*-test for small samples was used in determining significance of the data. The probability values were obtained from the tables in Yule and Kendall (21).

TABLE IV

COMPARISON OF LATENCIES ON THE FIRST DAY, ON THE DAY ON WHICH TEN ERRORS WERE MADE, AND ON THE LAST DAY

The upper figure in each cell is the mean latency in seconds on the reinforced trials; the lower figure, the mean latency on non-reinforced trials.

| Groups | Latencies on First Day | | Latencies on 10-error Day | | Latencies on Criterion Day | |
|---|---|---|---|---|---|---|
| | Initial | Transfer | Initial | Transfer | Initial | Transfer |
| Inhibitor | 9.7 | 16.4 | 7.9 | 10.0 | 5.6 | 6.3 |
| Alley | 7.8 | 18.4 | 42.9 | 46.3 | 57.7 | 57.5 |
| Inhibitor | 13.7 | 10.4 | 2.3 | 6.6 | 2.2 | 2.1 |
| Box | 11.5 | 9.2 | 36.1 | 40.2 | 57.4 | 57.4 |
| Excitor | 6.2 | 7.2 | 4.7 | 10.0 | 3.9 | 5.8 |
| Alley | 11.8 | 27.8 | 43.9 | 42.8 | 57.7 | 58.1 |
| Excitor | 6.0 | 3.6 | 1.6 | 4.6 | 1.9 | 2.2 |
| Box | 13.5 | 12.6 | 38.6 | 34.9 | 57.6 | 57.7 |

Tables II and III have demonstrated transfer by a saving in learning the new discrimination. The probability of immediate transfer, classical Pavlovian test of the conditioned inhibitor's effect, is not great, since such transfer would be reduced by the intermediate six days habituation and response training. Means and standard deviations of errors made on the first day of discrimination are presented in Table V. It can be seen that the differences between initial and

TABLE V

NUMBER OF ERRORS MADE ON THE FIRST DAY OF DISCRIMINATION TRAINING

The first figure in each cell is the mean for the group and the second figure is the standard deviation. Transfer is indicated by smaller means in the transfer groups.

| Group | Initial | Transfer |
|---|---|---|
| Inhibitor Alley | 21.7±1.5 | 20.3±3.4 |
| Inhibitor Box | 21.0±2.0 | 21.1±2.5 |
| Excitor Alley | 20.3±1.0 | 14.1±7.4 |
| Excitor Box | 18.7±2.2 | 19.0±2.0 |

transfer groups are small and not always in the same direction. Analysis of the latency of the responses likewise failed to yield any convincing evidence of transfer on the first day.

While the previous discussion gave evidence of a transfer effect in terms of the saving in learning a discrimination and pointed out the absence of any appreciable immediate transfer, no measure of the amount of transfer was included. This is shown in Table VI in

TABLE VI

MEASURES OF AMOUNT OF TRANSFER IN TERMS OF THE PERCENT SAVING

Negative numbers indicate a loss rather than a saving.

| Groups | Percent Saving in Transfer Groups in: | | |
|---|---|---|---|
| | Days | Errors | Errors on First Day |
| Inhibitor Alley | 52.9 | 56.8 | 6.4 |
| Inhibitor Box | 50.0 | 50.9 | −0.4 |
| Excitor Alley | 82.0 | 88.1 | 35.4 |
| Excitor Box | 51.6 | 51.4 | −1.6 |

terms of the percent 'saving' in days, total errors, and errors on the first day. A negative percent indicates a loss rather than a saving. An estimate of the reliability of these percentages may be obtained by consulting Tables III and V. It may be concluded that there is a reliable saving of about 50% in number of days required to learn the discrimination and in the number of errors made in learning. There is a small, but unreliable saving in the alley groups in the errors made on the first day and an unreliable loss in the box groups.

2. *Transfer of Pre-Discrimination Response Learning.*

The question might be asked, is the transfer obtained a direct transfer of the habits of running and bar-pressing, rather than a transfer of discrimination? That is, does learning to run down the alley, followed by discrimination training on the alley, facilitate discrimination learning in the Skinner box simply because it increases the ease of learning to press the bar? To answer this question, the speed of learning the pre-discrimination responses of running and pressing was compared for the transfer and initial groups. The measure of learning speed for each animal was the total latency of the 50 trials on the two days of response training.[4] If the measure used

[4] The total latency rather than the mean latency was used, since it seemed inappropriate to give the mean latency of a series of trials which were decreasing in the form of a learning curve. Both measures give the same arithmetical results, of course.

is the number of trials to reach a criterion, comparable results are obtained. The means and standard deviations of the total latencies for each group are presented in Table VII, as well as the *t*-values of

TABLE VII

MEASURES OF RESPONSE LEARNING AND RELIABILITIES OF DIFFERENCES BETWEEN INITIAL AND TRANSFER GROUPS

The first figure in each cell of the first two columns is the mean and the second figure, the standard deviation.

| | Total Latencies of Response Learning Trials in secs. | | | |
|---|---|---|---|---|
| | Initial | Transfer | *t* | P |
| Inhibitor Alley | 393.3±192.2 | 389.6±186.4 | .04 | .47 |
| Inhibitor Box | 345.4±166.3 | 307.5±188.8 | .5 | .311 |
| Excitor Alley | 327.0±118.8 | 408.5±146.7 | −1.3 | .105 |
| Excitor Box | 333.2±146.9 | 279.2±138.6 | .8 | .217 |

the differences between initial and transfer groups. A minus sign before a *t*-value indicates that the difference is not in the direction to be expected if there were transfer. It may be seen that these differences are small and are not always in the same direction. No *t*-value reaches the 0.01 level of significance. It thus seems unlikely that the saving in learning the second discrimination is due to a similarity in the responses required in the two situations, since if this were true a saving in learning the responses themselves would be expected.

3. *Types of Errors.*

It was possible for an animal to make two types of errors in discrimination. On a reinforced trial, it could wait too long or run too slowly and thus have a latency more than 10 sec. On a non-reinforced trial, it could run too soon, and thus have a response latency less than the required 60 sec. The errors of waiting too long on reinforced trials will be referred to as delay errors, the errors of not waiting long enough on non-reinforced trials will be referred to as non-delay errors. In the conditioned inhibition groups, delay errors could occur only when the buzzer was not on, and non-delay errors only when the buzzer was on. The reverse was true of the conditioned excitation groups, delay errors occurring when the buzzer was on, and non-delay errors when it was not.

TABLE VIII

NUMBER OF DELAY AND NON-DELAY ERRORS

The first figure in each cell is the mean for the group and the second figure the standard deviation. Transfer is indicated by smaller means in the transfer groups.

| Group | No. of Delay Errors (Errors on Reinforced Trials) | | No. of Non-delay Errors (Errors on Non-reinforced Trials) | |
|---|---|---|---|---|
| | Initial | Transfer | Initial | Transfer |
| Inhibitor Alley | 18.0±10.1 | 18.2± 7.5 | 181.4± 74.0 | 67.9±31.3 |
| Inhibitor Box | 11.9±11.2 | 9.5±13.2 | 183.1±127.7 | 85.6±60.8 |
| Excitor Alley | 10.9± 6.8 | 5.5± 5.5 | 260.7± 69.2 | 26.7±18.2 |
| Excitor Box | 5.4± 4.1 | 2.9± 2.1 | 214.8±148.8 | 103.9±63.5 |

In Table VIII the means and standard deviations of the delay and non-delay errors are given for all groups. It may be observed that every group made more non-delay errors than delay. This would be expected from the two days practice that is given on the positive response previous to introduction of discrimination. The fact that there are any errors on reinforced trials is probably due to generalization of extinction. Though it may be seen that, in general, the initial groups made more errors of both kinds than the transfer groups, there is considerably less difference in the case of the delay errors. Table IX gives the *t*-values of these differences and the

TABLE IX

RELIABILITIES OF DIFFERENCES IN TYPES OF ERRORS BETWEEN INITIAL AND TRANSFER GROUPS

The upper figure in each cell is the *t*-value of the mean difference between initial and transfer groups. The lower figure gives the probability that these differences could have arisen by chance.

| Group | Delay Errors | Non-delay Errors |
|---|---|---|
| Inhibitor | −.05 | 4.2 |
| Alley | .48 | <.001 |
| Inhibitor | .4 | 2.1 |
| Box | .347 | .025 |
| Excitor | 1.9 | 9.8 |
| Alley | .039 | <.001 |
| Excitor | 1.7 | 2.1 |
| Box | .056 | .025 |

probabilities that they are due to chance rather than to the experimental variable. Only the reduction in the number of non-delay

errors in alley groups satisfies the criterion of significance. Both differences and *t*-values are larger for non-delay than for delay errors in all groups.

## Discussion

This experiment has demonstrated that positive transfer effects occur when a rat which has been trained to discriminate between the presence and absence of a buzzer in one situation is required to make the same discrimination in a different situation. It remains to analyze the results to determine whether or not the conditioned inhibitor and conditioned excitor are responsible for the transfer.

This can be determined by comparing the amount of transfer shown on reinforced and non-reinforced trials, that is, in the presence and in the absence of the conditioned inhibitor or excitor. If there were more transfer on trials on which the buzzer was present than on trials on which it was not, conditioned inhibitor transfer groups should show a greater reduction in errors over initial groups on non-reinforced than on reinforced trials, while conditioned excitor transfer groups should show a greater reduction in errors on reinforced than on non-reinforced trials. From Table VIII, it may be seen that this expectation is confirmed in the inhibitor groups but not in the excitor groups, since excitor transfer groups actually showed a greater reduction in errors on non-buzzer than on buzzer trials. Two conclusions may be drawn: 1. Transfer in the excitor groups must be due to some factor other than the conditioned excitor. 2. The fact that the greatest reduction in errors occurs on non-reinforced trials in both excitor and inhibitor transfer groups vitiates an interpretation of the reduction in inhibitor groups as due to the effect of the conditioned inhibitor. Since the inhibitory effect ascribed to the conditioned inhibitor, i.e., the reduction in errors on non-reinforced trials, occurs under comparable conditions when no conditioned inhibitor, defined by the experimental arrangements under which it is established, is present, some other factor must be assumed to be active. Since conditioned inhibitors and excitors, therefore, can not be assumed to mediate the transfer, is it possible to discover what mechanism is responsible for transfer?

1. The results might simply be due to a transfer of general *adaptation*, of familiarity with handling, with being fed at regular hours, etc. To eliminate this possibility, the animals were given extended periods of handling before training was begun in order to habituate them to the general experimental situation. That this procedure was effective in eliminating the effects of general adaptation may be judged from a comparison of the pre-discrimination learning times as shown by Table VII. Were this factor important, a decrease in

time to learn the original response, previous to the introduction of discrimination training, would be expected in the transfer groups. This expectation is not borne out by the data.

2. Another possibility which might be suggested to explain the results is that a general '*faculty*' for discrimination has been trained. In this case, transfer would be of the most general sort, the buzzer and other stimuli being completely unimportant. The only similarity in the two situations would be the task set, that is, the requirement to discriminate between two stimuli. Such a theory would demand that the same results be obtained even if the stimuli used were completely different—a discrimination between a buzzer and absence of buzzer in one situation should show transfer to a second discrimination involving a light and tactual cue. While no direct test of this theory is included in the present experiment, it can be discarded on the basis of its failure to predict the greater transfer on non-reinforced trials.

3. An explanation which is more dependent upon similarity of stimulating conditions than the preceding hypotheses suggests that what is transferred is a *general attitude of caution.* The stimuli mediating the transfer would be any which would serve to identify the total situations as similar, such as the buzzer, handling by the experimenter, food reward, etc. The development of such an attitude of caution should favor the learning of any choice task, since presumably it involves attention to the discriminatory cues. It has been shown that forcing animals to wait before making a choice decreases learning time (**3**, **10**, **11**). Data from the two animals which had to be rejected because of inability to learn the first discrimination showed that when drive was reduced by feeding just prior to training, the discrimination was learned almost immediately.

If it is assumed that a general attitude of caution can facilitate the learning of a discrimination, it would be expected to do so by increasing time at the choice point (in this experiment, when either positive or negative stimulus is presented). This would serve to increase the latency on both reinforced and non-reinforced trials, and consequently might favor elimination of errors on non-reinforced trials, i.e., errors of running too soon, but might actually interfere with elimination of errors on reinforced trials, i.e., errors of waiting too long. While this would be in line with the greater transfer on non-reinforced trials, a comparison of latencies in Table IV shows that there is no consistent difference between transfer and initial groups.

4. Transfer might have occurred because of *generalization of not-responding.* It was shown that transfer occurred on non-reinforced trials but not on reinforced trials. This would suggest that while

there was no transfer of positive responses, there was transfer of negative. The stimuli mediating this transfer might be assumed to be presence of buzzer in the case of the conditioned inhibitor groups and the contrasting absence of buzzer in the case of the conditioned excitor groups. A comparison of the interaction of the negative responses before discrimination was begun, as in the case of the positive responses, could not be made. A demonstration, therefore, that learning not-to-press-a-bar will facilitate learning not-to-run-down-an-alley must depend on indirect proof. Since both involve inactivity to some degree, it might be expected that learning one would facilitate the learning of the other. The basic assumption that must be made, however, is that, in general, negative responses show wider generalization to other responses than do positive. Williams (**20**) suggested that "the slope of the generalized extinction gradient is less steep between two given points on a continuum than is the slope of the generalized reinforcement gradient." He felt, however, that his results offered ambiguous support for the inference. Liberman has pointed out the advantages of such an hypothesis from a theoretical point of view and has obtained some results verifying his position (**7**).

To recapitulate, since there is transfer on non-reinforced trials and not on reinforced, it may be inferred that buzzer in the inhibitor groups and absence of buzzer in the excitor groups are stimuli mediating a transfer of negative responses. The transfer of the negative response in contrast to the positive may be due to the similarity of the responses of not-running and not-pressing or to a tendency for inhibitory responses to show wider generalization to other responses. Basically, the transfer is a transfer of a specific response associated with a specific stimulus. The important thing is that the specific response is a negative response which can generalize widely. The statement might be made that any stimulus which has been associated with non-reinforcement (the response to which is a not-responding) would tend to inhibit the response to another stimulus with which it was associated, since it would elicit its own not-responding response. Thus, stimuli which have suffered extinction, or have been the negative cues in a discrimination (as the absence of buzzer in the conditioned excitor groups) would be expected to have the same inhibiting effect as a conditioned inhibitor. The statement that all stimuli which have been associated with non-reinforcement will inhibit the responses to another stimulus with which they are presented can be deduced from already known conditioning principles and for this reason is preferable to a description in terms of conditioned inhibition which is only an experimentally observed fact. Further, a conditioned inhibition explanation implies

that the inhibiting effect of the conditioned inhibitor is dependent upon the peculiar arrangement of the stimuli, while actually this experiment suggests that it is only due to the conditioned inhibitor's association with non-reinforcement.

The preceding discussion thus leads to the conclusion that the transfer of discrimination is best accounted for in terms of a transfer of not-responding. The original question of whether or not the transfer might be due to the presence of a conditioned inhibitor or excitor has been answered in the negative. It has been pointed out that, while a conditioned-inhibition effect, i.e., inhibition of the response to the stimulus with which the conditioned inhibitor was associated, was found, it was not due to the peculiar arrangement of the stimuli, as would be implied by a conditioned-inhibition explanation, but to the fact that the conditioned inhibitor was associated with non-reinforcement. Therefore, if the factors found responsible for the transfer in this experiment could have been operating in previous experiments on transfer of conditioned inhibition, it may be possible to 'explain' the conditioned inhibition effect in terms of more general learning principles.

If Pavlov's experiment is referred to again, it will be seen that there is no reason why the conditioned inhibitor cannot be considered a specific conditioned stimulus, the learned response to which is not-responding, in the same way as the buzzer and absence of buzzer in this experiment. The inhibiting effect of the conditioned inhibitor could thus be due, not to the peculiar arrangement under which it was established, but to its action as a stimulus eliciting its own response of not-responding when presented with another stimulus. As discussed previously, and from the results of this experiment, it might therefore be concluded that *any stimulus which has been associated with non-reinforcement will have the same inhibitory effect on the responses to other stimuli as a conditioned inhibitor.*

An analogous interpretation of conditioned excitation might be made. That is, *any stimulus whose learned response interacts with the response to another stimulus in such a way as to facilitate it, may be called a conditioned excitor.* This could be true of any conditioned stimulus, the degree of exciting effect being dependent entirely upon the nature of the response interaction. In the present experiment, there was no response interaction and the exciting effect was zero. It would be expected that it would always be more difficult to get conditioned excitation than conditioned inhibition since it is assumed that positive responses are less widely generalized than negative. However, it would be possible by extensive training of a particular stimulus in a number of reinforced situations to increase the gener-

ality of response to it to such an extent that its response generalization would be as wide as that of an inhibitory stimulus. Such widely generalized exciting stimuli are familiar in every-day life, as the loud tone of command, prestige signs, and so forth.

The above discussion redefines the concepts of conditioned excitation and conditioned inhibition in such a way that the particular experimental arrangement, which is unimportant, is excluded, and emphasizes instead the facilitating or inhibiting function of the response conditioned to the stimulus.

## Summary

Two discrimination situations were set up in such a way that there could be transfer from one to the other and this transfer could be mediated by a conditioned inhibitor or conditioned excitor. Four groups of 10 rats each were given training in the two discriminations, the cues for discrimination being presence or absence of a buzzer. In conditioned inhibition, the buzzer was the negative cue, while in conditioned excitation, it was the positive cue. Of the two groups used to test conditioned inhibition, one learned first to run down an alley to the positive cue and to inhibit running to the negative cue. The animals were then transferred to an experimental box where they learned to press a bar to the positive cue and to inhibit bar-pressing to the negative cue. The second conditioned inhibition group started in the box and subsequently was transferred to the alley. Each group thus served as a control for the other group. The same procedure was employed with the two conditioned excitor groups. In all groups, the habits of bar-pressing and running were learned before the discrimination was introduced.

1. All transfer groups made fewer errors and took less time to learn the discrimination, with a saving of about 50 percent over the initial groups.

2. Transfer groups did not show any improvement over initial groups in learning the pre-discrimination habits of running the alley and bar-pressing. This indicates that the transfer of discrimination was not based on a similarity of the responses used.

3. Both conditioned inhibition and excitation transfer groups made significantly fewer non-delay errors (responding on non-reinforced trials) than their initial groups, while the smaller reduction in delay errors (failing to respond on reinforced trials) was not significant.

4. Conditioned inhibition transfer groups thus showed more transfer when the buzzer was sounding than when it was not, while the reverse was true of the excitor transfer groups. The fact that the greatest reduction in errors occurred on non-reinforced trials in both

excitor and inhibitor transfer groups, i.e., independent of the presence of a conditioned inhibitor or excitor, vitiates an interpretation of the transfer of discrimination as due to a transfer of specific conditioned inhibition and excitation.

5. The results are discussed in terms of the generalization of 'not-responding' and the concepts of conditioned inhibition and conditioned excitation redefined in such a way as to bring them into accord with other learning principles.

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# EXTINCTION AND BEHAVIOR VARIABILITY AS FUNCTIONS OF EFFORTFULNESS OF TASK *

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This study deals with two distinct but related problems. The first is that of the relationship between the energy or effort involved in performing a habit and the rate at which this habit extinguishes (through non-rewarded repetition). The second problem is that of the relationship between the effortfulness of a habit and the tendency shown by living organisms to vary the behavior involved in the execution thereof.

Growing evidence indicates that extinction is a motivated adjustment in which fatigue plays an important role (**24**). If this be true, it follows that the extinction of an effortful habit will proceed more rapidly than will the extinction of a relatively effortless but otherwise comparable habit. Is this expectation empirically confirmed, and if so, what, precisely, is the relationship between the factor of effortfulness and the rate at which extinction occurs?

It has repeatedly been noted that in situations in which there are two or more equivalent ways of reaching the same goal, living organisms do not readily fixate on one of these ways to the exclusion of the others, but instead continue, often for a very long time, to vacillate between the available alternatives. Since this form of behavior variability is something of a paradox from the point of view of any simple conception of habit formation, we raise a second question: Is this form of behavior variability, or oscillation, in any way related to the absolute level of effort which the affected organism must exert in reaching the goal?

Although there is some disadvantage from an expository standpoint in considering these two problems in the same study, there is the compensating advantage that, by using an appropriate experimental design, both problems can be investigated at the same time with only slightly more inconvenience than either would occasion if attacked alone; and there is, moreover, a theoretical connection between them which will be more evident if the two problems are considered together rather than separately.

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The problem of the effortfulness of task in relation to extinction will be considered first, then that of effortfulness in relation to behavior variability, and finally their interrelationship.

## Part I. Extinction and Effort

Following the lead of Thorndike (**33**), the traditional assumption has been that reward strengthens and punishment weakens a habit. But of these two 'Laws of Effect,' only the principle of reward has been found to be fundamental, for through it the phenomena subsumed under the principle of punishment can be derived. It is, for example, a familiar fact that a hungry animal, which has learned to obtain food by pushing a bar, can be made to abandon this habit if a sufficiently strong electric charge is put on the bar. Superficially, it does indeed appear that the 'punishment' received when the bar is touched specifically weakens the original bar-pressing habit; but closer analysis shows that what actually happens is that the new motive, namely shock, merely calls forth a response which is incompatible with the original adjustment to the hunger motive, namely, the response of withdrawing from the bar, instead of pushing it. A *conflict situation* is thus produced in which the adjustment to the new, more urgent motive becomes dominant, without, however, necessarily weakening the original habit, *except in the sense of overlaying or superseding it.* Both of these responses are acquired, presumably, on the basis of the law of reward (reduction of hunger, reduction of shock), and the inhibitory effect is due to the fact that the responses are mutually incompatible, and unequally instigated.

For some years it has been known that 'punishment' is not, however, the only means by which habits can be inhibited: they can also be inhibited by their own non-rewarded repetition. Various hypotheses have been advanced as to the explanation of this effect; but in the present paper the assumption is made that the inhibition of a habit through non-rewarded repetition, i.e., by 'extinction,' works in fundamentally the same way as does inhibition through 'punishment.' In extinction the competing motivation is, we assume, the *fatigue* which is created by the organism's own activity; whereas in so-called punishment, the competing motivation is externally imposed. The adjustment demanded by punishment may take the form of withdrawal or avoidance, behavior which is necessarily incompatible with the action which occasioned the punishment. On the other hand, the adjustive behavior to the discomfort (fatigue) produced by the organism's own activity is simply that of resting, or inactivity; but this behavior is also incompatible with the continued performance of the original response. In both cases new

responses are thus instigated and reinforced which interfere with and, if sufficiently strong, inhibit the initial behavior. The modification of behavior, produced by the fatigue motive, is, we assume, basically the same as that produced by any other competing ('punishing') motive.[1] Both extinction and punishment, therefore, involve conflict between two or more responses which are differentially instigated.

The theory that extinction is a result of the interference of one habit by another has been previously suggested by Guthrie (**10**) and by Wendt (**38**), who explain the inhibition as rivalry between different reaction systems. These writers did not, however, recognize fatigue as the specific cause of the rivalry. Pavlov (**30**) has considered fatigue as a possible explanation of extinction but discarded it for what seem to us to be quite insufficient reasons. Brodgen, Lipman, and Culler (**2**), finding that three times as many trials were required to extinguish a conditioned response in dogs as to establish it (with electric shock as the unconditioned stimulus), have conjectured that "the only incentive for extinction is inertia. The dog might keep on reacting forever were it not easier now and then to stand still" (**2**, p. 112). Though fatigue is not stressed by these three writers as the explicit cause of extinction, it is nevertheless distinctly implied. The interference, or conflict, theory of extinction which is subscribed to in this paper (*cf.* Mowrer (**24**), Miller and Dollard (**23**), and Hull (**18**)) has the advantage of making possible a single, comprehensive explanation of the inhibition produced both by so-called punishment and by extinction, and leaves no need for positing a separate theory of 'adaptation' as proposed by Hilgard and Marquis (**17**) or the 'central inhibitory process' of Pavlov (**30**).

## Problem

If fatigue be the motive for extinction, it follows that the rate of extinction should be positively correlated with the effortfulness of the task, that is, the rate at which the fatigue is generated. The verification of this inference is the principal objective of the first part of this study.

[1] For present purposes, "fatigue," or "effort," may be defined as the internal stimulation which results from the contraction of skeletal muscles. This stimulation may be either specific or general; and it may be weak or strong. Specifically, "fatigue" refers to the stimulation of the particular muscles, tendons, and joints which are involved in the execution of any given reaction, in its more general aspect, it refers to the diffuse effects produced by the spread (through the blood stream) of the waste products of the local action. Both types of stimulation are stronger (a) if the reaction is performed against much rather than little resistance, (b) if the reaction is performed repetitively rather than singly or sporadically, and (c) if the organism is under-nourished, aged, arthritic, or diseased. The specific, localized stimulus-effects of action, if weak, serve mainly as cues for guiding action (kinesthesis); only when this and the more generalized form of action-produced stimulation becomes relatively intense does it take on motivational power, i.e., function as "fatigue."

## Apparatus

A front view of the apparatus employed in this experiment may be seen in Fig. 1a. This apparatus is made of wood with a glass front and wire flooring. The inside measurements are approximately 12 × 12 × 6 in. The food trough is located in the center of the back panel midway between two brass bars (¼ in. in diameter) which extend horizontally into the box a distance of 4½ in. Guards were installed over the bars to prevent the animals from climbing over and standing on them, thus ensuring a more uniform type of operation. Each bar required a minimum downward pull of five gm. and an excursion of approximately ½ in. to activate the

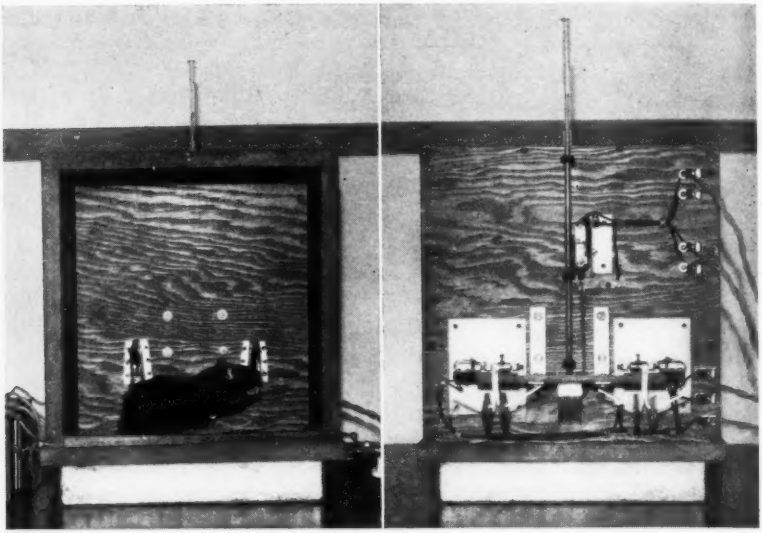

Fig. 1a and 1b. Front and rear views of apparatus used in this study.

electrical food-delivery mechanism which is located on the back of the apparatus (Fig. 1b). A description of this delivery mechanism will be found in an article by Mowrer and Miller (26). The food used in this experiment consisted of two parts Purina Dog Chow and one part macaroni flour, molded into cylindrical pellets approximately ¼ in. long and ⅛ in. in diameter. In order to secure the varying degrees of effort required to depress the bars, at different stages in the experiment, lead weights were added in appropriate number to the yokes attached at the opposite ends of the bars (see Fig. 1b).

## Subjects and Training Procedure

Thirty Lashley-strain female rats (four to six months old) were reduced and held for the duration of this investigation to 15 percent below normal body weight. The animals were given eight days of habituation to the apparatus, to the type of food used as reinforcement, and to being handled. During this time they also learned to push each of the two bars as a means of obtaining food. The detailed procedure was as follows. In order to accustom the animals to finding food in the trough, they received 20 pellets a day for two days with both bars absent. On the third and fourth days this procedure was repeated but with *E* clicking the electrical delivery mechanism so that the animals would learn to associate the sound of the click with the delivery of the food (32). On the fifth day one bar was inserted and each animal was required to depress it in order to receive a pellet of food. To preclude any tendency for position or recency

to act differentially on the establishment of preference, half of the animals were given access to the right bar on this day and half to the left. The bars were alternated during the sixth, seventh, and eighth days at the end of which time each animal had thus made a total of 80 rewarded responses, 40 on the right bar and 40 on the left. Beginning on the ninth day, both bars were left in the apparatus, a response on either producing a pellet of food.[2]

The remainder of the training procedure is graphically represented in Fig. 2. The amount of effort required to push the bars on the ninth day was the same as on the previous days, namely,

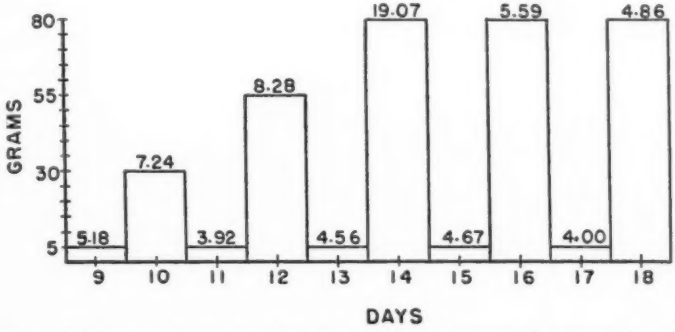


FIG. 2. Diagrammatic representation of procedure used to teach *Ss* to press bars requiring varying amounts of effort. The values given at the top of each column represent the average times (in minutes) required by all *Ss* to make the 20 responses constituting each day's training performance.

5 gm. On the tenth day, however, the difficulty of the task was increased to 30 gm. This was reduced to 5 gm. on the eleventh day and increased to 55 gm. on the twelfth. Again there was a return to 5 gm. on the thirteenth day, and this weight was alternated with 80 gm. for the remaining five days of the training period.[3]

The alternation between the 5- and 80-gm. levels of difficulty was continued until the animals took very little longer to perform 20 responses under the one condition than under the other. Indicated on the top of each column of the diagram shown in Fig. 2 are the average times required each day by all animals to make the 20 responses. These times are shown in minutes and hundredths of minutes. As training progressed, we see that the time involved in making the 20 80-gm. responses declines until, in the end, it is only slightly greater than the time required to make 20 5-gm. responses.[4]

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[2] For purposes of the part of this study which has to do with extinction and effort, one bar would have served as well as two. The double bar arrangement was made necessary by the second part of the experiment having to do with behavior variability.

[3] This peculiarly complicated procedure seemed necessary for the following reasons. If all *Ss* had been trained to press the bar with only one level of effort involved, there was the danger that they might have been differently affected by the three levels of difficulty used in extinction (quite aside from the direct effects of the effort factor), because a particular level of difficulty during extinction happened to be similar to or different from the one used during acquisition. On the other hand, if all animals had been trained with the bar response requiring the same level of effort during acquisition as was to be required during extinction, there would presumably have been variations in the resistance to extinction shown by the three groups, even if tested under precisely the same extinction conditions. The procedure actually adopted avoids both of these difficulties.

[4] The increment in the time required to make 20 5-gm. responses on the thirteenth and fifteenth days over that required on the eleventh day may be accounted for as follows. On the twelfth and fourteenth days the effort demanded was 55 and 80 gm. respectively. It was noticed that on a day following one on which the task had been unusually difficult, the animals were at

## Extinction

Up to this point all the animals had received identical treatment. They were now, on the nineteenth day, randomly divided into three groups. For one group the bars henceforth required 5 gm. of effort, for the second an intermediate amount of 42.5 gm., and for the third, 80 gm. On each of the three days immediately following acquisition training, each animal was placed in the apparatus and allowed to remain for 20 min. During this time the animal was free to make as many bar-pressing responses as it chose, but since the food delivery mechanism contained no pellets, no food was received as reward. The number of responses made during each of these extinction test periods was carefully recorded.

## Results

Fig. 3 shows the extinction curves for each of the three groups of animals on the three extinction days. That effortfulness of the task

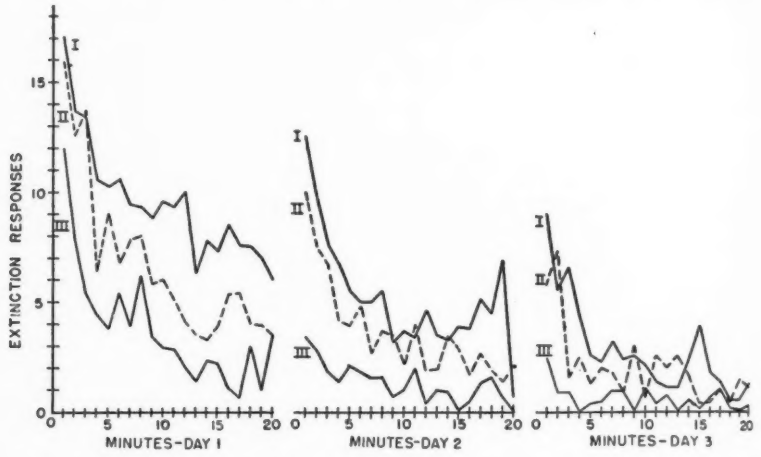


Fig. 3. Curves showing the course of extinction of a habit when that habit is easy (I), hard (III), and intermediate (II) with respect to the effort required to execute it.

is inversely related to the number of extinction responses is indicated by the finding that Group I, for which the task was easiest (5 gm.), clearly made the greatest number of responses; Group III, for which the task was most difficult (80 gm.) made the smallest number of responses; and Group II, with a task of intermediate difficulty (42.5 gm.), made an intermediate number of responses. Even in the first minute of non-rewarded repetition the effect of the effort-

first reluctant to start work. They would look at both bars, explore a bit, and finally push with much more energy than the task demanded. Consonant with the Law of Least Effort, however, this excessive exertion was gradually reduced to correspond to the demands of the task. By the seventeenth day learning was so far advanced that there was no hesitation in responding immediately, regardless of the level of difficulty, and the time required to make the 20 responses on this day was again practically the same as it had been on the eleventh.

fulness of the task was noticeable since the 5-gm. group made an average of 17 responses in the first minute, the 42.5-gm. group an average of 15.9 responses, and the 80-gm. group an average of 12 responses. On the last day of extinction the curves naturally draw together and show some overlapping as complete extinction is approached by all three groups.

Another way of presenting the results obtained in this study may be seen in Fig. 4, which shows the average number of responses made

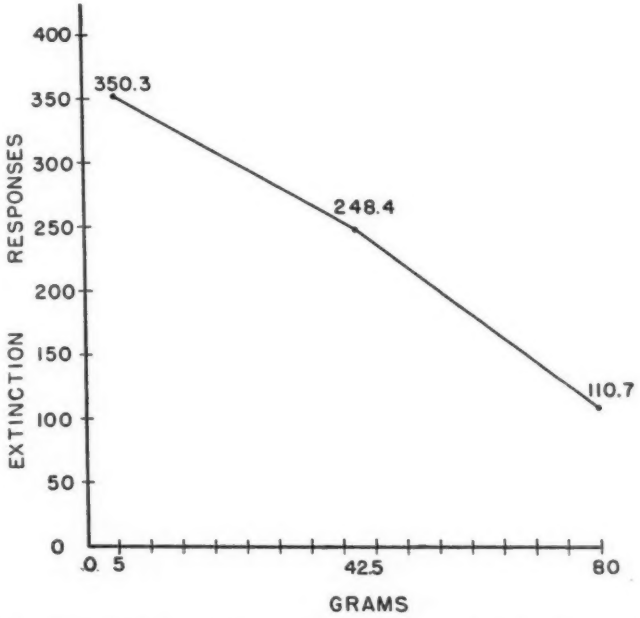


FIG. 4. Curve showing the average number of responses made during three standard extinction periods as a function of the effortfulness of the task.

by each group during all three extinction days. The 5-gm. group made an average of 350.3 responses during this entire period, the 42.5-gm. group an average of 248.4 responses, and the 80-gm. group an average of 110.7 responses. That these results are statistically significant is indicated by the finding that for the 5-gm. and 42.5-gm. groups the critical ratio is 1.93, for the 42.5- and 80-gm. groups it is 2.69, and for the 5-gm. and 80-gm. groups it is 8.00. All of these values are significant at the 0.05 level or better. From these results the hypothesis is clearly confirmed that extinction is related to the effortfulness of the task.

One striking, but not unexpected, incidental result of this experiment was that during extinction individual differences among the animals were found to be a function of the degree of effort involved. The behavior of the 5-gm. extinction group was surprisingly uniform, but in the 42.5- and 80-gm. groups some animals showed signs of frustration and aggression, consisting of excessively vigorous pressing of the bar, gnawing at the guards and other parts of the apparatus, jumping, and other agitated behavior. Using the coefficient of variation, $V = \frac{100\sigma}{M}$, it was found that for the 5-gm group, $V = 1.95$, for the 42.5-gm. group, $V = 5.73$, and for the 80-gm. group, $V = 5.16$. Calculating the coefficient of variation without a Group II aberrant animal which made more responses than did any animal in Group I, the $V$ for the 42.5-gm. group is then 4.1, thus showing a progressive increase in variability as the effort of the task was increased. This is consistent with the results of previous investigations by Mowrer and Lamoreaux (**25**) and Whiting and Mowrer (**41**) which disclosed individual differences to be greater when a learning task is difficult than when it is easy.

## Discussion

Fig. 3 suggests a problem which the fatigue theory of extinction has to face. If it is the response of resting which interferes with the original response of pushing the bar, and if it is admitted that fatigue disappears with rest, then why do not the three curves start at the same point on the three days of extinction? Why, on the second day, does the bar-pressing start at a lower level for all three groups than on the first, and on the third day at a still lower level than on the second?

This phenomenon may be accounted for in the following manner. During acquisition the response of pressing the bar had been followed by a reduction in hunger and so has been reinforced. At the same time it has also been connected with the cues of the total situation, such as the click of the food-delivery mechanism, the lights and shadows in the box, the odors of the apparatus, and so on. The whole pattern of stimuli provided by the apparatus has thus acquired some capacity for producing the bar-pressing response through the principle of associative reinforcement (**24**). During extinction, however, the response of pushing the bar does not result in hunger reduction; whereas the response that does get reinforced is resting. The situational stimuli which had previously become connected with the bar pressing response now become connected with the resting response. In other words, the sign-function, or 'meaning,' of the experimental situation changes from place-where-rat-reduces-hunger-

by-pressing-bar to place-where-rat-gets-tired-and-has-to-rest. It is, then, this shift due to associative learning that causes the animals to respond differently on successive extinction days even though the hunger motive is held constant and the oppositing fatigue motive is also approximately the same at the beginning of each daily experimental session. Extinction is thus seen to be a true, though somewhat complicated, learning function (*cf.* Hull (**18**) and Miller and Dollard (**23**)).

It is interesting to note that if the curve shown in Fig. 4 were extrapolated to the right, it would cross the baseline at about 110 grams, thus suggesting that with the bar response requiring this amount of effort, extinction would be immediate and complete, i.e., that the task would be so arduous that the animals could not perform it at all. If, on the other hand, the curve were extrapolated to the left—to the point where the bar-pressing required, hypothetically, no effort at all—extinction would occur at about 373 responses. If our hypothesis—that the fatigue, or effort, generated by the non-rewarded repetitions of a habit is the cause of extinction—be valid, then one would be forced to predict that a habit requiring zero effort should occur an infinite number of times. Why, then, does the curve shown in Fig. 4 suggest a finite number of responses at zero effort?

Obviously the 5 gm., 42.5 gm., and 80 gm. required to press the bar during extinction do not represent all of the work done during the extinction period. Also effortful are raising the fore-legs to the bar to depress it, going to and from the food trough, etc. The amount of effort consumed in these actions is not directly measurable; but fortunately the extent of this effort can be at least roughly estimated. Since 5 is one-sixteenth of 80, one would be led to expect the 5-gm. group to make sixteen times as many responses as did the 80-gm. group, if bar-pressing were the only source of fatigue or effort. But from the number of extinction responses made by these two groups, it would appear that the work performed by the 80-gm. group was only about three times, rather than 16 times, as great as that performed by the 5-gm. group, since the latter made three times as many responses. Evidently a constant factor should be added to the 5 and 80 which makes the total amount of effort involved for the 80-gm. group only three times that of the 5-gm. group. If 32.5 is added to 5, the result is 37.5. This amount multiplied by 3 is 112.5. If 32.5 is added to 80 the result is likewise 112.5. The effort exerted by the 80-gm. group per trial would thus be three times that exerted per trial by the 5-gm. group. It may be assumed, therefore, that the effort involved in getting in position to push the bar, going to look for food, etc., is about 32.5 gm., irrespective of the effort directly involved in pushing the bar. If, therefore, the graph shown in

Fig. 4 were shifted to the right 32.5 units, there would then be the requisite amount of space on the left for the curve to be deflected upward toward infinity in accordance with the expectations of this theory.

## Part II. Variability and Effort

The results which have just been described are in complete accord with findings previously reported by Crutchfield (**3**), Fitts (**8**), James (**19**), and Brogden, Lipman, and Culler (**2**) and with the general conception of the Law of Least Effort as formulated by Wheeler (**40**) and with Hull's Law of Less Work (**18**). More novel are our results concerning the relation between effortfulness of task and behavior variability.

In a situation in which there are two or more ways of attaining the same goal, living organisms often behave in such a manner as to create a learning-theory paradox. On the first trial, the goal will be reached by one particular means or route. This fact indicates an initial preference for this in contrast to the other alternatives. And since the alternative which is initially selected leads to reward, this preference should be further enhanced, with the result that the organisms' performance would be promptly and permanently fixated. But this, as even the most causal observation will indicate, is rarely what occurs: instead of the initial response, or response-series, being immediately stereotyped,[5] the organism usually continues to show a considerable, though eventually diminishing, amount of exploration and response variations. How is this interesting, and biologically significant, phenomenon to be explained?

It was formerly the practice to refer to the varied responses which an organism displays in a trial-and-error learning situation as *random*, i.e., as due to uncontrollable and unpredictable circumstances. But as Miller and Dollard (**23**) and other recent writers (**24**, **31**) have shown, the successive responses which are made in such a situation occur according to a pre-determined order, or hierarchy, and each unsuccessful ('erroneous') response ('hypothesis') gives way in turn to the next because of the inhibition (conflict) produced by its own non-rewarded repetition. That variation should occur among *unsuccessful* responses is thus well accounted for, but the question remains as to why living organisms should vacillate between two or more *successful* responses.[6] In situations in which the alternative

[5] See Guthrie and Horton (**11**) and Cutsforth (**4**) for studies reporting unusually prompt stereotyping. See also Whiting and Mowrer (**41**) for a discussion of the role of anxiety in producing 'curiosity' behavior.

[6] Also implied is the question as to why living organisms show variations in the particular movements, or actones (*cf.* Murray (**29**)), involved in performing what, from a molar standpoint, is the *same* act or habit. This kind of variability is obviously related to the ability to eliminate awkward, unessential movements and to develop 'skill.'

adjustments involve unequal amounts of effort or reward, one can see an evolutionary, or survival, value in an organism's being able to manifest at least enough variation to insure discovery of the best solution. Such a statement does not, however, offer an *explanation* of the phenomenon in question for the reason that it does not designate the relevant variables, or determinants. Presumably the same determinants as cause this 'adaptive' variation in behavior are also responsible for the ostensibly 'non-adaptive' variability that occurs between alternative adjustments of equal merit. At least this is the hypothesis which prompted the experimentation shortly to be described.

In commenting upon the objectively useless variability which occurs in the behavior of organisms in situations where there are two or more precisely equivalent routes to the same goal, various writers have suggested that this phenomenon may be due to an inherent tendency on the part of nervous tissue to vary or fluctuate in its functioning in such a way as to produce the instability noted in overt behavior. Thorndike, for example, says:

"There are subtle differences in the brain and nerves and muscles of the individual from minute to minute which cause a multiplicity or variety of responses to the same external situation" (**34**, p. 10).

A similar conception is implied by Maier and Schneirla, who say:

"The order in which these reactions appear may depend upon the excitatory threshold of each manner of response, or it is possible that the responses are an expression of a tendency to vary behavior" (**22**, p. 119).[7]

Most explicit and complete is Hull's recent discussion. This writer, positing a "spontaneous oscillation in irritability of the neural conduction elements which mediate behavior" and a "random and spontaneous firing of the individual neurons throughout the nervous system" (**18**, p. 310), has formulated the following formal postulate:

"Associated with every reaction potential ($_sE_r$) there exists an inhibitory potentiality ($_sO_r$) which oscillates in amount from instant to instant according to the normal 'law' of chance, and whose range, maximum, and minimum, are constant" (p. 319).

It is indeed unlikely that any nervous system would be capable of preserving exactly the same level of excitability, or reactivity, from day to day or even from moment to moment. But recourse to this imperfection of nervous functioning as an explanation of the type of behavior variation which is here under consideration seems somewhat premature. The older assumption that the response variation which

[7] *Cf.* Krechevsky (20), Adams (1), Gengerelli (9).

occurs in trial-and-error behavior was due to 'chance' served only to obscure a problem and delay its solution. To the present writers, the use of such terms as 'chance,' 'random,' and 'spontaneous' in attempting to explain behavior oscillation in situations involving various routes to the same goal can only arouse the suspicion that here again we may be employing language which provides nothing more than a pseudo-solution.[8] Since the concept of inhibition through the non-rewarded repetition of responses has provided an apparently valid explanation of response variability in trial-and-error situations, a thoroughgoing attempt should be made to account for the variability which occurs in trial-and-no-error situations on the same basis before resorting to any hypothetical neurological explanation which, as Hull warns, generates a certain fatalism as to the possibility of ever achieving "precise prediction of the specific behavior of any organism at any given moment" (**18**, p. 318).

The justification for invoking a dubious neurological hypothesis to explain behavior oscillation decreases still further when we note that no less than seven methods have previously been described whereby this phenomenon can be experimentally manipulated. Elliott (**6**) has shown that rats vacillate between five alternate routes to food significantly less when very hungry than when only slightly or moderately hungry (*cf.* Hamilton (**13**)). Hamilton and Krechevsky (**15**) and Everall (**7**) report that the administration of an electric shock before the point of choice in a T-maze creates a marked tendency toward 'perseveration,' i.e., loss of normal variability ('plasticity'); and Everall (**7**) finds that temporal delay produces a similar effect. Hamilton and Ellis (**14**) describe a loss of variability following experimentally induced brain lesions. Pavlov (**30**), Hamilton (**13**), Witkin (**39**) and others have advanced evidence that 'distraction' also increases response variation. Krechevsky and Honzik (**21**) and Hall (**12**) find that response vacillation is a function of level of learning, being, in general, greatest in the early stages and least in the later stages. Heathers (**16**) reports that vacillation between two alternative routes to equivalent goals (in a T-maze) is greater when trials are massed than when distributed and suggests an explanation in terms of Dodge's conception of 'refractory phase' (*cf.* Dennis (**5**)). If response vacillation is thus subject to modification by such a

[8] This statement is intended to apply no less to situations in which the alternative routes or ways of reaching the goal are unequal than to those situations in which the alternatives are equal. The so-called Law of Least Effort, as variously formulated by Wheeler (**40**), Gengerelli (**9**), Tsai (**36**), Waters (**37**), and others, undoubtedly provides a descriptively correct statement of the tendency of living organisms to select, other things being equal, the least effortful means of solving the problem. (See also Adams (**1**).) But more fundamental is the question which we pose: How to explain the response variation which must occur before a 'selection' may be said to have been made.

variety of means, appeal to a neurological explanation (which really does not explain but merely replaces one mystery by another) appears to be quite unnecessary.[9]

## Problem

As previously noted, the mechanism which is responsible for extinction seems to operate as a 'self-correcting' device whereby living organisms are forced (without external interference, or 'punishment') to abandon useless (unrewarding, wrong) behavior and to try out other, possibly more efficacious (rewarding, right) responses. It would seem reasonable to suppose that the same mechanism is probably also responsible for the variations in behavior which occur when there are two or more (either equally or unequally good) routes to the same goal. Since 'wrong' responses which are effortful extinguish more quickly than do relatively effortless responses (see Part I) and since effort is required in making 'right' responses no less than in making 'wrong' ones, it would seem to follow that, other things being equal, the more effortful the alternate routes to a goal, the greater should be the tendency for living organisms to become extinguished ('refractory') with respect to one of the routes and therefore likely to resort to the other, thus showing a pattern of successive alternations, or oscillation. As the results reported below indicate, this, however, is too simple a view of the matter.

## Results and Discussion

It will be recalled that in order to determine the effects of effort on rate of extinction, we trained our *S*s according to the special procedure described in the first part of this study (see Fig. 2). This procedure provided for a 10-day training period during which the level of effort required to execute the rewarded task was varied on successive days as follows: 5, 30, 5, 55, 5, 80, 5, 80, 5, 80 gm. Since two strictly equivalent bars were available throughout this period, the procedure used in connection with our first problem provided an excellent opportunity for also testing the hypothesis just advanced that when equivalent responses are equally effortful living organisms vacillate between them more, i.e., show less stereotyping, than when the responses are relatively effortless. A careful record was accordingly kept during this 10-day period of the order in which all animals chose the two bars which were thus available to them in making the

[9] If one attempts to explain the apparent capriciousness of living organisms in choosing alternate routes to the same goal in terms of 'spontaneous' neural oscillations, it would be equally logical to try to account in the same way for the 'vicarious trial-and-error behavior' (VTE) which occurs at choice points in mazes and in discrimination learning. Far from being a kind of *paralysis agitans*, this behavior has been shown by a variety of researches (27, 28, 35) to be a definite aid to economical learning, which is probably itself a product of earlier learning.

20 responses which were permitted each day. In Fig. 5 will be seen the results, first of all, in terms of the amount of vacillation (percentage of trials on which there was a shift from one bar to the other) which occurred each day. Contrary to our expectations, it was found that this phenomenon was related in no detectable manner to the level of effort required to execute the bar-pressing task. The only consistent trend was a gradual decrease in the amount of vacillation from the beginning to the end of this period.

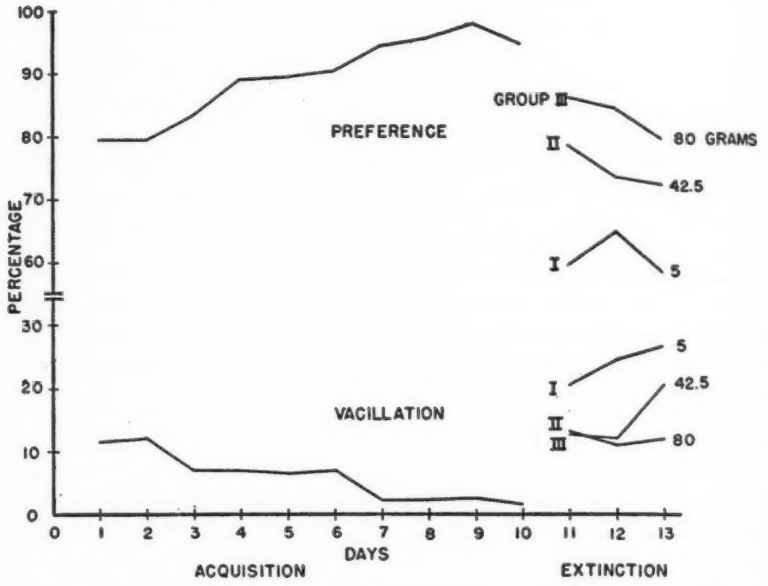


FIG. 5. Curves showing two measures of response variability (vacillation and preference) as functions of level of effort involved. During the 10 days of acquisition, the effort factor was varied as follows: 5, 30, 5, 55, 5, 80, 5, 80, 5, 80 grams without, however, affecting either measure of response variability. During extinction, on the other hand, when the effort factor was varied by groups but not from day to day, there is a clear indication of causal relationship.

As might have been expected, it turned out that preference for a given bar (measured in terms of the percentage of trials on which each animal selected its favored bar) was inversely related to the vacillation measure just described (see upper curve in Fig. 5), but this measure likewise failed to show any perceptible effect of the day-to-day variations in the level of effort required to perform the bar-pressing task. In keeping with the inverse relationship between these two measures of variability, there was, however, a gradual increase in the stability of preference during the 10-day period.

Since the procedure employed in the first part of this study readily permitted it, the tendency to vacillate between the two equivalent bars was recorded not only during acquisition but also during extinction, with highly interesting results. By referring to Fig. 5 it will be seen, in the first place, that during extinction both the vacillation and preference measures show trends exactly the reverse of what they showed during acquisition. (It will be remembered that all the animals had received the same training up to the beginning of extinction but were then randomly divided into three groups; during extinction we therefore have three curves for each of these measures instead of only one as during acquisition. In other words, during the acquisition training variations in effortfulness of task were introduced on successive days as already indicated; whereas, during extinction, the variations in effort were introduced in terms of the three groups, I, II, and III.) In the second place, the weight factor does have a decided effect on both preference and vacillation during extinction, in contrast to the absence of effect during acquisition. As can be seen from the curves shown in Fig. 5, the 80 gm. group showed the least vacillation, the 5-gm. the most, with the 42.5-gm. group intermediate; but although the effect of effort is thus clearly reflected, it is in a direction opposite to what had been anticipated. As we see, the more arduous the task during extinction, the higher is the preference for one particular bar and the lower the vacillation between the two bars, whereas we had originally assumed that the greater the effortfulness of the task the lower would be the preference and the greater the amount of vacillation.

In an unpublished experiment carried out some years ago by the senior author and Mr. William D. Orbison, it was likewise found that when rats were allowed to run to a common goal *via* either of two equivalent maze routes, they showed reliably less vacillation when these two routes were both relatively long than when they were both short. But since the factor of effort cannot be varied in a maze situation without also varying the time factor, these results were not taken as necessarily disproving the hypothesis that, with other factors held constant, effortfulness and variability should be positively correlated. However, since the results of the present experiment, in which the time factor was held virtually constant (see Fig. 2), also fail to show the expected positive correlation, the hypothesis can be regarded as definitely disproved.

An explanation of the finding that under at least certain conditions behavior variability is negatively, rather than positively, correlated with effortfulness of task has not yet been fully worked out; but one possibility is that the inhibitory effects generated by the repeated performance of a task generalize more strongly to a similar or equiva-

lent task when these tasks involve a high degree of effort than when they involve a low degree of effort. Most of the work which has been done on generalization has had to do with *stimulus* equivalence; further research on the laws governing the generalization of equivalent *responses* may or may not confirm the foregoing conjecture. However, in showing that under at least some circumstances the effort factor is capable of influencing response variability we have added another variable to the seven previously listed by means of which response variability can be experimentally controlled and to this extent have further discredited the type of neurological hypothesis previously advanced by various other writers.

## Summary

This study takes as its point of departure the hypothesis that the elimination of a response, or habit, through its own non-rewarded repetition involves a conflict in which the fatigue thus generated instigates a response (resting) which is incompatible with and therefore tends to inhibit the original response. Such an hypothesis is confirmed by the finding that the rate at which a non-rewarded response extinguishes is highly correlated with the effortfulness of that response. It is also confirmed by the well known tendency for an extinguished response to reappear after a lapse of time since the motive which produces the inhibitory response of resting, namely fatigue, is thereby eliminated. The fact that the amount of recovery following successive extinctions becomes progressively smaller and may eventually reach zero is due to a change in the 'meaning' of both situational and organic cues, which follows familiar learning principles.

If extinction be thus conceived as a 'self-correcting' mechanism (in principle no different from 'punishment'), by means of which behavior which has previously been but is no longer rewarding is eliminated, then the role of extinction in producing the response variation which is so essential in trial-and-error learning becomes obvious. But living organisms not only manifest and then abandon 'erroneous' responses; they also often show considerable variability in situations in which there are two or more equally 'correct' responses. If only one motive were involved in situations of this kind, the observed response vacillation would be quite incomprehensible; but since we know that fatigue is generated no less by the performance of responses which lead to reward than by those which do not (assuming that they occur equally often), one is justified in supposing that the resulting conflict, or 'ambivalence,' is in some way responsible for the capriciousness just mentioned. Since the effortfulness of a response is known to be positively correlated with the

rapidity with which that response extinguishes if reward is withdrawn, it was conjectured that the more effortful two alternative routes to the same goal, the greater would be the 'ambivalence' toward each route and the greater the tendency to vacillate between them. The experimental results here reported do not, however, confirm this expectation. Alternative hypotheses are considered, which will be tested by later research.

(Manuscript received October 6, 1943)

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# CHROMATIC PHENOMENA PRODUCED BY INTERMITTENT STIMULATION OF THE RETINA

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## INTRODUCTION

The classical formulations of the relationship between experience and stimulation have largely neglected the dimension of time. In other words, to borrow some terms from physics, these formulations have concerned themselves principally with what might be called the 'steady state' phenomena. But the 'transient' phenomena, of which, in vision, the Fechner-Benham colors are an example, present a problem of certainly greater difficulty and theoretical importance. Neglect of the 'transient' phenomena encourages theorizing in terms of functional 'atoms' of the form: stimulus—excitation—sensation. With the blessing of the Doctrine of Specific Energies, the inevitable result is a body and soul (receptor, central projection and 'sensation') theory, logically no better than the body and soul theories of the most ancient tradition.

The experiments herein reported constitute an attempt to penetrate a little further into the mysteries of those visual 'transients' known as the Fechner-Benham colors and certain other apparently closely related phenomena.

Originally discovered by Fechner (**8**), the phenomenon was popularized by Benham (**3**), who devised the now usual method of producing the colors. This consists of a disc which is half black and half white, on the white part of which are segments of concentric black rings (Fig. 1A). When rotated clockwise the inner rings appear reddish and the outer rings bluish. Reversing the direction of the rotation reverses the coloration of the rings.

The colors observed in the rings are apparently dependent upon the speed of rotation, the lengths and widths of the concentric rings and other physical variation in the stimulus pattern (**2**, **16**, **17**).

Related to the Fechner-Benham phenomena are the colors producible in stationary stimulus patterns, involving, as with the discs, adjacent black and white areas. The Luckiesh-Moss line pattern (**15**)—Fig. 1B—and the Skinner disc pattern (**20**)—Fig. 1C—give

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rise to a series of complex perceptions of color and movement when steadily fixated.

The interpretations of the Fechner-Benham phenomena due to rotating discs are of two types. The general form of the first postulates different latencies of several photochemical processes of the

FIG. 1A. Benham disc

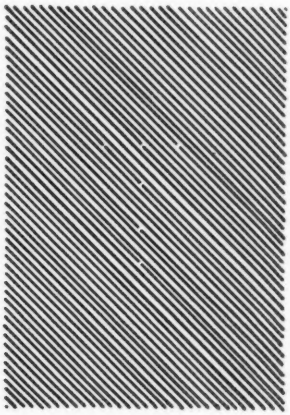

FIG. 1B. Luckiesh-Moss line pattern

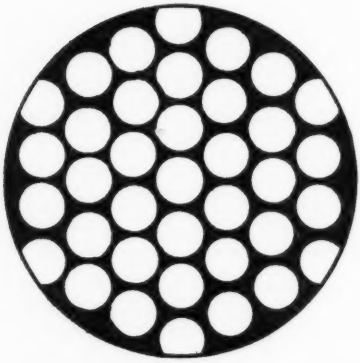

FIG. 1C. Skinner disc pattern

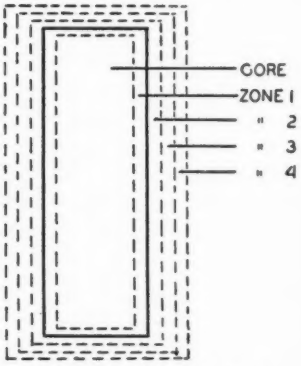


FIG. 1D. Zoning effect

receptor mechanism. These processes, when stimulated, do not begin and cease to respond at the same speeds: their excitation curves reach their maxima and minima at different rates. Thus the different degrees of participation of these chromatic components in the total effect will depend upon the temporal and spatial aspects of the stimulus pattern (3, 8, 9, 17).[1]

[1] For detailed summaries see Bagley (2), Piéron (17) and Erb and Dallenbach (7).

The second type of theoretical approach is based by Fry (**10**) on the modulation theory of Troland (**22**). Fry attempts to show that the Fechner-Benham phenomenon depends on the principle of a "complicated stimulus pattern which involves the stimulation of adjacent areas of the retina with different temporal patterns of intermittent white light." He holds that the Fechner colors are compatible with Troland's theory on the basis that intermittence alone [2] will produce colors and that the classical Benham disc provides merely a special pattern of intermittence.

As yet only a few suggestions have been made to explain the color perceptions from the stationary patterns. Erb and Dallenbach (**7**) investigated the bearing of eye movements on the colors and concluded that "the 'subjective' colors are to some extent dependent upon eye movement, but eye movement, though necessary, does not appear to be a sufficient or compulsory condition." They also state that the colors are enhanced when fixation is not in the plane of the figure.[3] Skinner (**20**) suggests an explanation for the colors seen on his disc pattern which hypothesizes a disproportionate activity in the cone processes and hence the same effect as that of stimulation by colored light.

Both the revolving discs and the stationary patterns have been observed under chromatic as well as neutral illumination. The few studies available, however, have contributed little to the general theory (**1**, **17**, **18**).

## Apparatus

The results of previous investigations suggest that an indispensable physical condition necessary for the production of the Fechner colors is some form of intermittent or variable stimulation of the retina. They also suggest that the phase relation between the intermittent stimulations of adjoining regions of the retina is an important modifying factor. The Benham top and the stationary pattern both fulfill this condition, the one by alternate dark and light flashes produced by the black and white sectors and the other by some complex of eye movements which causes oscillatory shifting of the stimulus pattern on the retina. However, a much wider latitude for experimental variation of conditions is gained by an arrangement which provides independently variable illuminations of figure and ground in a stationary pattern, in contrast with the Benham disc, where the ratio of the luminosities of the bright and dark regions is fixed, no matter what the absolute level of the illumination may be. If it is possible in the case of these fields to vary (1) the luminosities independently, (2) the frequencies of intermittence over a continuous range up to the critical flicker frequency, (3) the on and off ratios independently, and (4) the phase relationships, all variations in the physical conditions involved in the production of the phenomena in question can be arranged. To this end the apparatus described in detail elsewhere in this Journal was adapted (**4**). Here will be given only a brief sketch of the stimulus arrangement serving the left eye, the eye used in all experiments to be discussed.

The left ocular, *Lf* (Fig. 2), consists of an arrangement of flashed opal diffusing surfaces, $f$, $F_1$ and $F_2$. These are independently illuminated by 240-watt, d.c., GE airplane headlight lamps ($L_1$, $L_2$ and $L_3$) which, when mounted with a set of appropriate lenses, provide a powerful light source. The flashed opal surfaces are visible to the eye of the observer at $X$ by virtue of

[2] See Purkinje, J. E. (**19**), Ch. I, Vol. I.

[3] Further evidence of this implied blurring factor is offered later in the present paper.

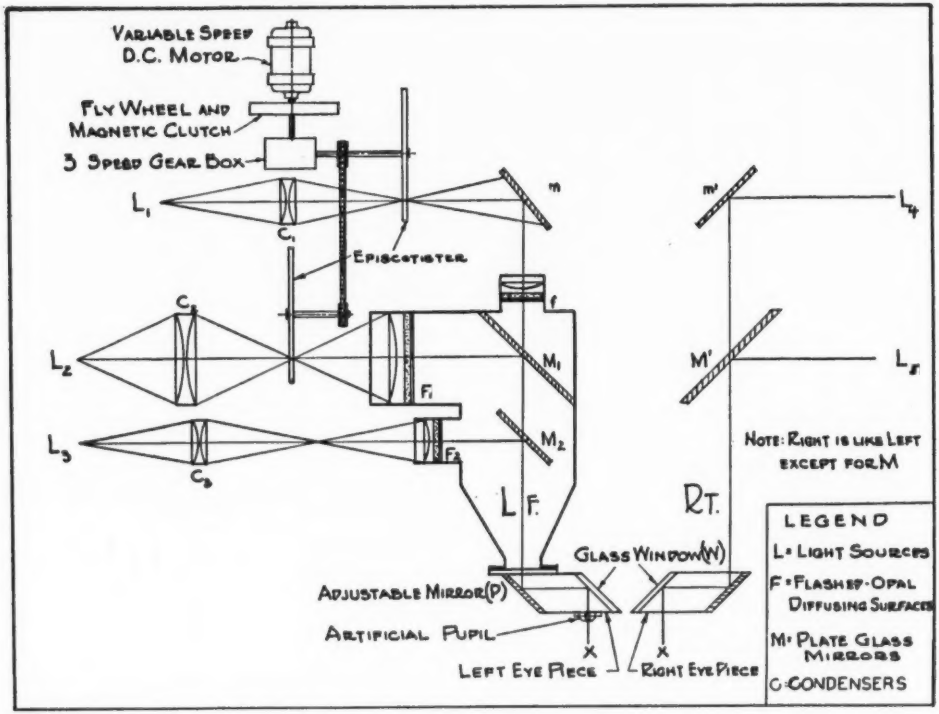


FIG. 2. Apparatus for presentation of stimulus

the mirrors $m$, $M_1$ and $M_2$, which are placed at 45° angles with respect to the optical axis of the system. An area of silver of any size or shape may be scraped from the backs of $M_1$ and $M_2$ and thus three fields are provided: $F_1$ and $F_2$, whose images are seen in $M_1$ and $M_2$, and $f$, which is seen directly through $M_1$ and $M_2$. Any combination of these three fields may be arranged by removing certain of the mirrors, by using partially silvered mirrors, or by using mirrors which have been desilvered over certain areas.

The mirrors $M_1$ and $M_2$ are mounted in a large cylindrical tube in which is sealed a mineral oil whose refractive index (1.481) is approximately that of the glass in the mirrors (1.517). By making the system optically homogeneous any reflex images occasioned by differences in refractive indices are eliminated. The oil is held in the tubes by glass retaining windows and the surfaces $f$, $F_1$ and $F_2$ are placed in optical contact with them by a film of oil.

In the eye-piece attached to the tube an adjustable mirror ($E$) for centering the field is located. This sends the light to a glass window which with total reflection passes the light into the eye of the observer. The external orifice of the eye-piece may be fitted with artificial pupils of any desired aperture.

The optical system just described produced a maximal field brightness of 501 millilamberts as determined by standard photometric means. Neutral filters of the proper density were used to produce lower field brightnesses.

When set up for the actual experiments only $m$ and $M_1$ were used. The silver was removed from a small circular area on the back of $M_1$ so that light from $m$ could be seen through $M_1$. The small circular spot, elliptical as seen through the eye-piece, since $M_1$ sets at a 45° angle to the optical axis of the tube, thus constituted a figure seen against the ground provided by $M_1$. Two episcotisters were placed in the paths of $L_1$ and $L_2$ to cut the light at the point of focus. This expedient achieved the sharpest cutoff. The episcotister discs consisted of two open and two closed 90° sectors which could be shifted with respect to each other to change the phase relationships between the on and off periods of the figure and the ground. The episcotisters were coupled by a chain and sprocket system to maintain synchronism and were driven by a large, variable speed, d.c. motor equipped with a 28-pound fly wheel to eliminate short period fluctuations. Speed of rotation of the episcotisters was governed by a three-speed gear box and a set of resistances in series with the motor. The number of flashes per sec (F.P.S.) could be continuously varied from one flash per sec. to 60.

Three kinds of illumination were used: almost white, unfiltered light; red; green.

To obtain red light suitable for this investigation it was necessary to be certain that the filter used would transmit no radiation of wave length shorter than 650 mμ. Wave lengths longer than 650 mμ probably stimulate the postulated G retinal process negligibly, if at all, and hence should involve the R process only. The Wratten No. 89 red filter fulfills this condition. Photometric calibration of the particular filter used gave its transmission factor as .0025. This filter provided a field brightness at $M_1$ of 1.25 millilamberts.

A green filter which transmits a narrow band of light is difficult to find, and from a physiological standpoint no green illuminant, however monochromatic, stimulates the G retinal process only: the R and B processes will be affected. However, a green filter constructed in accordance with Gibson's specification was employed. Gibson (15) used a combination of glasses which transmits light at 560 mμ:

(*a*) Corning: 351, 4.55 mm. in thickness.
(*b*) Corning: didymium, 5.82 mm. in thickness.
(*c*) Jena: VG −3, 1.99 mm. in thickness.
(*d*) Jena: BG −18, 1.94 mm. in thickness.

This combination has, according to Gibson, a spectral centroid of 560 mμ for any daylight or incandescent illuminant. The transmission factor of the green filter was .0237, which yielded a brightness at $M_1$ of 11.8 millilamberts.

In the experiments to be described the conditions of observation were the same. The position of the *S*'s head was determined by an adjustable head rest and a tooth bit so that the left eye always occupied the same position with respect to the eye-piece. The eye-piece was enclosed with a black cloth, the ends of which *S* arranged about his eye so that no light except that from the eye-piece could enter the left eye, and no light at all, the right.

The three *S*s used were observers of considerable experience. Two had spent many hours in observing such visual effects. The third was less practiced, although he had had some previous experience in the process of observing and describing the Fechner colors.

*Observer A.*—(The least practiced.) Male. Age 26. Myopic, slight astigmatism. Wears glasses. Left eye correction: −2.25. Normal trichromat.

*Observer B.*—Male. Age 28. Myopic, slight astigmatism. Wears glasses. Left eye correction: −2.50. Normal trichromat.

*Observer C.*—Male. Age 48. Myopic, pronounced astigmatism. Presbyopic. Wears glasses. Left eye correction: −2.25. Normal trichromat.

After adaptation to the brightness level of the instrument the *S*s described what they saw at the position of the figure and on the surrounding field. The colors were reported in accordance with instruction in the color naming system which makes red-orange (RO), for example, a color which lies spectrally between the reds and the oranges and contains more orange than red. The series of notations used by *S* and recorded by *E* was: R—OR—RO—O—YO—OY—Y—GY—YG—G—BG—GB—B—VB—BV—V. The symbol for purple was P; for white, W; for black, Bl; for gray, A (achromatic); for Brown, Br. In cases where complex phenomena were observed, *E* made labeled diagrams representing the pattern of the effects described by the *S*s. These were checked by *S*.

## Procedure and Results

### *Part I*

*Preliminary Observations with White, Red and Green Light.*—With $M_1$, a mirror with a circular hole .189 in. in diameter, an extensive series of episcotister speeds and phase settings were tested. Under all conditions the figure and the ground were equal in brightness and their illuminations were qualitatively alike.

Schedule of speeds and settings used in Part I:

1. Frequencies of 2, 4, 6, 10, 15 and 20 F.P.S.
2. Phase lead of ground over figure: 18°, 36°, 54°, 72° and 90°.
3. Phase lead of figure over ground: 18°, 36°, 54° and 72°.

Subjects A and B.

With white light of maximal field brightness (501 millilamberts) good colors were observed on the figure under nearly all conditions (Table I). These were mostly desaturated yellows and greenish yellows, although a few greens, greenish blues and violets were noted. Changes in flash frequency and phase relationship had no consistent effect on colors observed, nor did the *S*s agree well on what they experienced under the same conditions. A condition of decreased illumination (7 millilamberts) yielded about the same results, except that the predominant yellows at the high illlumination gave way to greens (Table II).

Since the transmission factor of the red filter used was low (field brightness 1.25 millilamberts), studies were made on white light of very low intensity for purposes of comparison. Two neutral filters of low transmission were used to obtain field brightnesses of 1.3 and .55 millilamberts. Under these conditions colors were reported by Subject B, but not by Subject A (Table III). They were principally variations of red with a few weak violets appearing at certain settings.

TABLE I

COLORS OBSERVED WITH WHITE LIGHT AT VARIOUS FLASH FREQUENCIES AND PHASE SETTINGS WITH ELLIPTICAL FIGURES

Figure and ground brightness: 501 millilamberts

| F.P.S. | Subject | Lead of ground over figure in degrees: | | | | |
|---|---|---|---|---|---|---|
| | | 18° | 36° | 54° | 72° | 90° |
| 2 | A | Y | GY | Y | Y | Y |
| | B | ? | O | G | ? | Y |
| 4 | A | Y | Y | G | G | Y |
| | B | Y | Y | YG | OY | G |
| 6 | A | Y | Y | Y | GY | G |
| | B | Y | Y | Y | OY | G |
| 10 | A | Y | Y | Y | Y | Y |
| | B | OY | OY | Y | Y | ? |
| 15 | A | OY | OY | O | OY | OY |
| | B | OR | O | O | YO | R |
| 20 | A | Y | Y | YO | OY | YO? |
| | B | YO | OY | OY | OR | R |
| | | Lead of figure over ground in degrees: | | | | |
| F.P.S. | Subject | 18° | 36° | 54° | 72° | 90° |
| 2 | A | — | — | Y? | Y? | Y |
| | B | V | V | ? | ? | Y? |
| 4 | A | Y | Y | YG | Y | Y |
| | B | V | B | ? | Y | YG |
| 6 | A | V | ? | YG | GB | G |
| | B | V | V or B | B | Y | G |
| 10 | A | — | — | YG | Y | Y |
| | B | V | GB | YG | YO | ? |
| 15 | A | — | — | YO | OY | OY |
| | B | V? | G | Y | OR | R |
| 20 | A | — | — | YO | Y | YO |
| | B | ? | V | YO | O | R |

Note: At the lower flash frequencies both the light and dark phases of the cycles were seen on the spot. Usually it was the light interval which was colored, the dark interval being achromatic.

Red light and green light tested under the phase and flash frequency settings described above yielded no colors other than red, in the case of the red light, and green, in the case of the green light, for Subjects A and B. When the above findings were checked by Subject C, however, extremely complicated color patterns were reported.

The observations of C differed from those of A and B in two fundamental respects:

*a.* C was able to see colors when approximately monochromatic illuminations were used, and

*b.* C was able to see, under all conditions of illumination, complex patterns of colors on and around the figure instead of a more or less homogeneously colored spot.

TABLE II

COLORS OBSERVED WITH WHITE LIGHT AT VARIOUS FLASH FREQUENCIES AND PHASE SETTINGS WITH ELLIPTICAL FIGURES

Figure and ground brightness: 7 millilamberts

| F.P.S. | Subject | Lead of ground over figure in degrees: | | | | |
|---|---|---|---|---|---|---|
| | | 18° | 36° | 54° | 72° | 90° |
| 2 | A | A | A | A | A | A |
| | B | A | A | G? | G? | A |
| 4 | A | BG | GB | A | A | A |
| | B | G | O | A | YG | YG |
| 6 | A | Y | Y | Y | Y | A |
| | B | G | G | G | G | YG |
| 10 | A | GB | GB | GB | G | GY |
| | B | G | G | G | G | G |
| 15 | A | — | — | A | A | Y? |
| | B | GY | G | G | G | G |
| 20 | A | — | — | — | A | A |
| | B | A | G | G | G? | G |
| | | Lead of figure over ground in degrees: | | | | |
| F.P.S. | Subject | 18° | 36° | 54° | 72° | 90° |
| 2 | A | Y | Y | Y | Y | A |
| | B | Y | Y | Y | YG | YG |
| 4 | A | Y | Y | Y | Y | A |
| | B | Y | Y | YO | YG | YG |
| 6 | A | Y | Y | Y | Y | A |
| | B | Y | Y | Y | YG | YG |
| 10 | A | Y | YG | YG | YG | GY |
| | B | A | A | G | G | G |
| 15 | A | — | Y | A | Y? | Y |
| | B | A? | GB? | G | G | G |
| 20 | A | — | — | — | A | A |
| | B | A | GB | G | G | G |

TABLE III

COLORS OBSERVED AT VARIOUS FLASH FREQUENCIES AND PHASE SETTINGS WITH WHITE LIGHT AND ELLIPTICAL FIGURES

Figure and ground brightness: 1.3 millilamberts

| F.P.S. | Lead of ground over figure in degrees: | | | | |
|---|---|---|---|---|---|
| | 18° | 36° | 54° | 72° | 90° |
| 2 | A | A | A | A | A |
| 4 | A | R? | R? | ? | A |
| 6 | — | R? | R | R | R |
| 10 | — | R | B? | P? | P? |
| 15 | — | — | — | — | V? |
| 20 | — | — | — | — | — |
| | Lead of figure over ground in degrees: | | | | |
| F.P.S. | 18° | 36° | 54° | 72° | 90° |
| 2 | A | A | A | A | A |
| 4 | A | O | O | R | A |
| 6 | P? | R | R? | R | R |
| 10 | V | V | V | V | R?B? |
| 15 | — | — | — | — | V? |
| 20 | — | — | — | — | — |

Figure and ground brightness: .55 millilamberts

| F.P.S. | Lead of ground over figure in degrees: | | | | |
|---|---|---|---|---|---|
| | 18° | 36° | 54° | 72° | 90° |
| 2 | A | A | A | A | A |
| 4 | A | A | R? | R | R? |
| 6 | A | A | A | R? | R? |
| 10 | A | A | A | B? | A |
| 15 | — | — | — | — | — |
| 20 | — | — | — | — | — |
| | Lead of figure over ground in degrees: | | | | |
| F.P.S. | 18° | 36° | 54° | 72° | 90° |
| 2 | A | A | A | A | A |
| 4 | A | R? | R | R | R? |
| 6 | A | P? | R? | R? | R? |
| 10 | A | A | A | A | A |
| 15 | — | — | — | — | — |
| 20 | — | — | — | — | — |

The contradictory data are not clearly to be accounted for by ocular differences between C and A and B, although it was these differences that suggested the following investigations. Possibly C's greater astigmatism, impaired accommodation and slight lens cloudiness might contribute to produce a somewhat diffuse illumination of

the retina. It is well known that blurring the boundary enhances simultaneous contrast and it was thought that reducing the sharpness of the boundary between figure and ground might similarly affect the perceptions.

*Part II*

*Reduction of Boundary Sharpness.*—A means for producing some blurring of the boundary of the figure was provided by placing small glass discs finely etched with levitated alumina in the eye-piece. The glass discs produce a 74 percent transmission loss. Comparable brightnesses without the blurring effects were obtained with appropriate filters.

Under these conditons both A and B reported colors when red and green illumination was used. They also reported the presence of colored borders with white light. Some degree of indistinctness at the boundary of figure and ground enhanced and complicated the chromatic phenomena observed with white light and produced colors under conditions of monochromatic illumination where they were absent before.

The border phenomena experienced with the elliptical figure were extremely difficult to hold long enough to observe and describe. The most assiduously maintained fixation proved to be insufficiently rigid to allow for careful observation. It was then thought that a long, straight boundary might afford more stable border effects than the small, curved boundary of ellipse. To this end, bars were formed by scraping the silver from the backs of the mirrors, just as in the case of the other figures. The bars were all 3/4 in. long and were at first of three widths: 1/16 in., 1/8 in. and 1/4 in. The 1/4 in. bar was presently discarded as providing nothing that was not observable in the 1/8 in. bar. The bars were presented with their long dimension vertical.

The preliminary observations indicated that little was gained by using flash frequencies of other than 6 and 10 F.P.S. and later investigations agreed with this finding. Nor were the phenomena observed with all the phase settings previously noted sufficiently distinct to warrant their use.

Schedule of speeds and settings used in Part II:

1. Frequencies of 6 and 10 F.P.S.
2. Phase lead of ground over figure: 18°, 54° and 90°.
3. Phase lead of figure over ground: 18° and 54°.

The extensive series of investigations conducted on the effects of the width of the bar and reduction of boundary sharpness yielded data which in the present state of these investigations can be pre-

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sented only qualitatively. The most unsatisfactory part of the experimental procedure on any work of this nature is the method of recording the observations. Not only are the phenomena themselves apt to become enormously complicated under certain conditions, but they are likewise so unstable and transitory as almost to defy characterization. Much was found to depend upon steady fixation and a vigorous attempt was made on the part of all three *S*s to describe the effects only when fixation was thought to be rigid. Nevertheless, despite the difficulty in getting accurate descriptions of the effects, certain findings are clear.[4]

*a. Zoning.*—The area of the figure and the part of the field immediately adjacent to it was found to divide itself symmetrically into a series of zones or bands parallel to the two lateral boundaries of the bars (Fig. 1D). This zoning effect was easily visible to Subject C, who discovered the phenomenon with the elliptical figure. It was not readily seen by Subjects A and B under ordinary conditions and in the preliminary experiments had been missed altogether. Blurring the boundaries of the figure, however, increased markedly the visibility of the zones and the number of them. This effect applied to the bars viewed under red and green light as well as with white light. The zones seen with white illumination were more varied in hue and more numerous than those observed with colored light, although Subject C, whose perceptions were somewhat more complex, reported quite involved patterns of bands with the red and green illuminations in many instances.

Tables IV, V and VI show typical arrangements of color perceptions observed with the bar figures, using white, red and green illumination of both bar and field. The tables show the coloration of the control core of the bar and one half of the surrounding zones extending outward toward the field. The zone formation on the other half of the bar is merely the arrangement indicated in reverse order.

To check on the zoning process and to ascertain that the reduction of boundary sharpness was primarily instrumental in producing the borders two sets of control series were arranged, both without blurring. In one, maximal figure and ground brightness was used for all three illuminants with the vertical bars. In the other, intensity of illumination was reduced to that occasioned by the transmission loss (74 percent) when the ground glass disc was used. For Subjects A and B these conditions produced no notable zoning effects and were comparable in this respect to the results of the preliminary experiments on the elliptical figure. For Subject C the zones were present just as in the case of the previous unblurred conditions.

[4] Thomsen (21) reports the same difficulties in analogous observations of intermittent light.

## TABLE IV

COLORS OBSERVED WITH WHITE LIGHT AT VARIOUS FLASH FREQUENCIES AND PHASE SETTINGS WITH BLURRED BAR FIGURES

Figure and ground brightness: 130 millilamberts *

1/8″ bar. 6 F.P.S.

| Region of Phenomena | | Core | | | | Zones 1 | | | 2 | | | 3 | | | 4 | | Field | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Subject | | A | B | C | A | B | C | A | B | C | A | B | C | A | B | C | A | B | C |
| Phase lead | Gd. over Fig. 18 | G | A | | W | A | | | V | | | | | | | | YG | Y | Y |
| | Gd. over Fig. 54 | Y | Y | A | A | V | B | | A | | | | | | | | W | Y | Y |
| | Gd. over Fig. 90 | Y | Y | GY | | W | GY | | V | V | | | B | | | | A | Y | Y |
| | Fig. over Gd. 54 | Y | Y | Y | Y | W | V | Y | V | | | | | | | | YG | Y | Y |
| | Fig. over Gd. 18 | Y | B | BG | R | W | V | | | | | | | | | | W | Y | Y |

1/8″ bar. 10 F.P.S.

| Region of Phenomena | | Core | | | | Zones 1 | | | 2 | | | 3 | | | 4 | | Field | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Subject | | A | B | C | A | B | C | A | B | C | A | B | C | A | B | C | A | B | C |
| Phase lead | Gd. over Fig. 18 | A | A | A | | V | | | | | | | | | | | W | Y | Y |
| | Gd. over Fig. 54 | YO | A | G | Y | R | V | A | Bl | P | | B | A | | V | B | GY | Y | Y |
| | Gd. over Fig. 90 | OY | GY | YG | | V | V | | | P | | | A | | | B | W | Y | Y |
| | Fig. over Gd. 54 | OR | Y | OY | W | V | V | | | Y | | | A | | | | YG | Y | Y |
| | Fig. over Gd. 18 | BG | V | G | | A | | | | | | | | | | | W | Y | Y |

1/16″ bar. 6 F.P.S.

| Region of Phenomena | | Core | | | | Zones 1 | | | 2 | | | 3 | | | 4 | | Field | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Subject | | A | B | C | A | B | C | A | B | C | A | B | C | A | B | C | A | B | C |
| Phase lead | Gd. over Fig. 18 | Y | R | YG | Bl | A | A | A | | | | | | | | | Y | Y | Y |
| | Gd. over Fig. 54 | Y | Y | GY | Bl | Bl | V | A | V | B | | | | | | | Y | Y | Y |
| | Gd. over Fig. 90 | Y | Y | Y | Bl | Bl | V | A | V | A | | | | | | | Y | Y | Y |
| | Fig. over Gd. 54 | Y | B | Y | A | Y | V | Bl | A | A | A | | | | | | Y | Y | Y |
| | Fig. over Gd. 18 | BV | B | G | Bl | W | | A | A | | | | | | | | Y | Y | Y |

1/16″ bar. 10 F.P.S.

| Region of Phenomena | | Core | | | | Zones 1 | | | 2 | | | 3 | | | 4 | | Field | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Subject | | A | B | C | A | B | C | A | B | C | A | B | C | A | B | C | A | B | C |
| Phase lead | Gd. over Fig. 18 | A | G | GY | | V | | | | | | | | | | | Y | Y | Y |
| | Gd. over Fig. 54 | OR | O | Y | Bl | B | GY | A | V | | | | | | | | Y | Y | Y |
| | Gd. over Fig. 90 | R | Y | Y | Bl | V | GY | A | | Bl | | | | | | | Y | Y | Y |
| | Fig. over Gd. 54 | R | Y | GY | Bl | A | V | A | | A | | | | | | | Y | Y | Y |
| | Fig. over Gd. 18 | A | B | BG | | W | B | | V | | | | | | | | Y | Y | Y |

* Tables IV, V and VI present the colors observed in the zones on the right half of the bar. This region corresponds to the arrangement in Fig. 3. The zones appear on both sides of the figure, one half being a mirror image of the other.

## TABLE V

COLORS OBSERVED WITH RED LIGHT AT VARIOUS FLASH FREQUENCIES AND PHASE SETTINGS WITH BLURRED BAR FIGURES

Figure and ground brightness: .33 millilamberts

1/8″ bar. 6 F.P.S.

| Region of Phenomena | | Core | | | Zones 1 | | | 2 | | | 3 | | | 4 | | Field | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Subject | | A | B | C | A | B | C | A | B | C | A | B | C | A | B | C | A | B | C |
| Phase lead | Gd. over Fig. 18 | R | P | G | R* | A | A | | | | | | | | | | R | R | Y |
| | Gd. over Fig. 54 | P | P | G | R | A | Y | | B | A | | A | V | | | A | R | R | Y |
| | Gd. over Fig. 90 | P | P | G | R | B | Y | | | A | | | V | | | A | R | R | Y |
| | Fig. over Gd. 54 | P | B | Y | | R | V | | A | A | | | | | | | R | R | Y |
| | Fig. over Gd. 18 | R | R | G | | | A | | | | | | | | | | R | R | Y |

1/8″ bar. 10 F.P.S.

| Region of Phenomena | | Core | | | Zones 1 | | | 2 | | | 3 | | | 4 | | Field | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Subject | | A | B | C | A | B | C | A | B | C | A | B | C | A | B | C | A | B | C |
| Phase lead | Gd. over Fig. 18 | R | P | G | | | R | | | V | | | | | | | R | R | R |
| | Gd. over Fig. 54 | R | P | V | O | R | GY | | R | Bl | | | | | | | R | R | W |
| | Gd. over Fig. 90 | P | B | O | OR | R | GY | | R | O | | | V | | | A | R | R | W |
| | Fig. over Gd. 54 | R | P | Y | O | R | Y | | A | B | | | | | | | R | R | Y |
| | Fig. over Gd. 18 | R | R | G | OY | | | | | | | | | | | | R | R | Y |

1/16″ bar. 6 F.P.S.

| Region of Phenomena | | Core | | | Zones 1 | | | 2 | | | 3 | | | 4 | | Field | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Subject | | A | B | C | A | B | C | A | B | C | A | B | C | A | B | C | A | B | C |
| Phase lead | Gd. over Fig. 18 | R | R | R | | | | | | | | | | | | | R | R | R |
| | Gd. over Fig. 54 | P | P | V | | A | | | R | | | | | | | | R | R | R |
| | Gd. over Fig. 90 | P | P | Br | R | R | A | | A | | | B | | | | | R | R | R |
| | Fig. over Gd. 54 | R | P | GY | | R | A | | | | | | | | | | R | R | R |
| | Fig. over Gd. 18 | R | R | R | | | | | | | | | | | | | R | R | R |

1/6″ bar. 10 F.P.S.

| Region of Phenomena | | Core | | | Zones 1 | | | 2 | | | 3 | | | 4 | | Field | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Subject | | A | B | C | A | B | C | A | B | C | A | B | C | A | B | C | A | B | C |
| Phase lead | Gd. over Fig. 18 | R | P | R | | | | | | | | | | | | | R | R | R |
| | Gd. over Fig. 54 | P | P | BV | | A | | | | | | | | | | | R | R | R |
| | Gd. over Fig. 90 | P | B | BV | | R | | | | | | | | | | | R | R | R |
| | Fig. over Gd. 54 | A | P | V | RO | R | | | | | | | | | | | R | R | R |
| | Fig. over Gd. 18 | R | R | R | | | | | | | | | | | | | R | R | R |

* In those instances in the table where a red boundary is shown adjacent to a field of the same hue, the zone is phenomenally brighter or darker than the field.

TABLE VI

COLORS OBSERVED WITH GREEN LIGHT AT VARIOUS FLASH FREQUENCIES AND PHASE SETTINGS WITH BLURRED BAR FIGURES

Figure and ground brightness: 3.08 millilamberts

1/8″ bar. 6 F.P.S.

| | | Region of Phenomena | Core | | | Zones 1 | | | 2 | | | 3 | | | 4 | | | Field | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | Subject | A | B | C | A | B | C | A | B | C | A | B | C | A | B | C | A | B | C |
| Phase lead | Gd. over Fig. | 18° | A | YG | A | | A | | | | | | | | | | | GY | GY | GY |
| | | 54° | BG | G | G | A | Bl | GB | | | R | | | | | | | GY | GY | GY |
| | | 90° | BG | YG | G | W | Bl | Br | | | | | | | | | | GY | GY | GY |
| | Fig. over Gd. | 54° | BG | YG | G | W | Bl | R | | | A | | | | | | | GY | GY | GY |
| | | 18° | G | YG | GB | | B | G | | | B | | | | | | | GY | GY | GY |

1/8″ bar. 10 F.P.S.

| | | Region of Phenomena | Core | | | Zones 1 | | | 2 | | | 3 | | | 4 | | | Field | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | Subject | A | B | C | A | B | C | A | B | C | A | B | C | A | B | C | A | B | C |
| Phase lead | Gd. over Fig. | 18° | G | G | | | V | | | | | | | | | | | YG | YG | YG |
| | | 54° | G | G | B | | YG | Br | | V | G | | | | | | | YG | YG | GY |
| | | 90° | BG | YG | B | W | G | G | | V | Br | | | | | | | YG | YG | GY |
| | Fig. over Gd. | 54° | G | YG | G | G | A | W | | | R | | | | | | | YG | YG | GY |
| | | 18° | G | YG | | | A | | | | | | | | | | | YG | YG | YG |

1/16″ bar. 6 F.P.S.

| | | Region of Phenomena | Core | | | Zones 1 | | | 2 | | | 3 | | | 4 | | | Field | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | Subject | A | B | C | A | B | C | A | B | C | A | B | C | A | B | C | A | B | C |
| Phase lead | Gd. over Fig. | 18° | G | G | A | | | | | | | | | | | | | G | GY | YG |
| | | 54° | B | G | GB | W | | BG | | | | | | | | | | YG | GY | YG |
| | | 90° | BG | G | G | | Bl | R | | | | | | | | | | G | GY | YG |
| | Fig. over Gd. | 54° | BG | GY | G | W | | R | | | | | | | | | | G | GY | YG |
| | | 18° | G | YG | GB | | A | G | | | | | | | | | | G | GY | YG |

1/6″ bar. 10 F.P.S.

| | | Region of Phenomena | Core | | | Zones 1 | | | 2 | | | 3 | | | 4 | | | Field | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | Subject | A | B | C | A | B | C | A | B | C | A | B | C | A | B | C | A | B | C |
| Phase lead | Gd. over Fig. | 18° | G | G | A | | | | | | | | | | | | | G | GY | GY |
| | | 54° | G | G | BG | | YG | G | | V | | | | | | | | GY | GY | GY |
| | | 90° | BG | G | B | G | YG | Br | | V | | | | | | | | GY | GY | GY |
| | Fig. over Gd. | 54° | G | O | G | G | YG | R | | G | | | | | | | | GY | GY | GY |
| | | 18° | G | R | | | YG | | | G | | | | | | | | G | GY | GY |

*b. Effect of width of figure on number of zones perceived.*—The number of zones produced by reduction of boundary sharpness was roughly related to the width of the bars investigated. The wider (1/8 in.) bar produced more zones on the whole than the narrow (1/16 in.) bar. There was, however, a condition with white light

for Subject A in which the narrow bar produced more phenomenal borders. Under the rest of the conditions and with all *S*s the wide figure produced slightly more numerous zones. A breakdown of Tables IV, V and VI is shown in Table VII. Here the number of

TABLE VII

ONE HALF NUMBER OF ZONES SEEN BY SUBJECTS A, B, C UNDER THE VARIOUS CONDITIONS PRESENTED IN TABLES IV, V AND VI *

| Width of Bar and F.P.S. | | White light | | | Red light | | | Green light | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | Subject | A | B | C | A | B | C | A | B | C | Total |
| 1/8" 6 F.P.S. | | 5 | 9 | 6 | 3 | 7 | 12 | 3 | 5 | 7 | 57 |
| 10 F.P.S. | | 3 | 8 | 11 | 4 | 6 | 10 | 2 | 7 | 6 | 57 |
| | Total | 8 | 17 | 17 | 7 | 13 | 22 | 5 | 12 | 13 | 114 |
| 1/16" 6 F.P.S. | | 11 | 9 | 7 | 1 | 6 | 2 | 2 | 2 | 4 | 44 |
| 10 F.P.S. | | 6 | 7 | 6 | 1 | 3 | 0 | 2 | 8 | 3 | 36 |
| | Total | 17 | 16 | 13 | 2 | 9 | 2 | 4 | 10 | 7 | 80 |

* The number of zones tabulated corresponds to the region indicated on the right side of Fig. 3. There are actually twice as many boundaries, since the zones are arranged symmetrically around the central core.

zones perceived for one side of the bar is presented according to the various conditions of the observations.

*c. Instability of the subjective borders.*—It has already been emphasized that the colored perceptions were most difficult to observe. Their fleeting, nebulous appearance is undoubtedly of the utmost theoretical importance. Of importance also is the observation that the various zones and their hues did not appear immediately for any of the observers, but took some seconds or even minutes to develop to what was judged to be their full form. During this developmental time they underwent much fluctuation and when at last they reached a more or less stable form [5] they were described by *S*.

*d. Long term development of subjective chromatic perceptions in observers.*—A factor related to the foregoing is the observation that the naive observer in these and similar stimulus situations (e.g., after-images, flight of colors) often sees little or nothing. With continued observation from day to day and week to week, however, the saliency and complexity of the perceptions grow.[6] How long this process continues is unknown. Two of the observers in these studies have been working on subjective color phenomena for several years and still occasionally unearth effects which are new to them.

[5] The term 'more or less stable form' is intentionally vague. It is doubtful if the subjective phenomena with which we are dealing here ever reach an entirely stable form. Observations of 10 to 15 min. duration disclosed continued slow fluctuations in the character of the borders.

[6] Ives (14) encountered a similar effect when studying the 'flight of colors.'

*e. Field phenomena.*—Accompanying the borders surrounding the bars was an impressive and beautiful array of field effects. These long-known phenomena (**19**) producible by intermittent light were not extensively investigated here, but were studied briefly to see if they bore any relation to the borders observed on the bars. Special investigations of these field phenomena will be discussed in another paper. It will be sufficient here to summarize briefly the findings:

(1) The surrounding field usually took on a characteristic desaturated hue after a few minutes of observation. The field hue accompanying the borders is given in Tables IV, V and VI.

(2) A ubiquitous violet cloud was observed to float about the center of the field and to influence the coloration of the zones whenever it crossed the region of the figure. Edridge-Green (**6**) has suggested that this cloud may correspond to the macula, made visible, somehow, by the filtering action of the yellow pigment. However, since the cloud moves about, it cannot well be due to macular pigment, which remains fixed.

(3) There were observed also a variety of mobile geometrical patterns too numerous to mention. These filled the entire central portion of the field and were present most of the time. All these and the above-mentioned phenomena were evident under all conditions of illumination and intermittence.

(4) The field effects were present under a condition where there was no figure in the field; i.e., $M_1$ with a desilvered area was replaced with a plain mirror. They were observable also with no intermittence, although they were very faint.

## Discussion

Two theories have been proposed to explain the fact that colors may be produced by the presentation of intermittent achromatic stimuli. One holds that the various photochromatic retinal processes have different starting and stopping times and that consequently different chromatic resultants have different 'resonance' frequencies. The other asserts that the colors are due to modulations of the optic nerve impulse volleys which result from complex temporal patterns of retinal stimulation.

*Inadequacy of the Temporal Lag Explanation.*—The chief difficulties of the lag theory are to be found in two facts:

*a.* Colors are producible under various conditions of stimulation with monochromatic red illumination so chosen as to act upon the R retinal process only. These conditions include intermittent figure-ground patterns and intermittent and steady homogeneous fields.[7]

[7] See also Abel (1) on the Luckiesh-Moss pattern.

*b.* The slow arousal of the zoning effect with blurring and the general instability reflected in the long term fluctuation of the zones.

Fry (**11**) attacks the temporal lag explanation of the mechanism of the Benham disc. If his demonstration is correct, the color is determined not by the position which the concentric arcs occupy relative to the leading edges of the black and white sectors, but rather by the particular temporal pattern of intermittence, determined by relative positions of all disc parts. If the internal relationships between the sectors and the rings are kept constant, shifting the rings with respect to the leading edges of the discs produces no different effects. Fry's finding is not clearly substantiated by the results presented here, although the reports obtained from Subjects A and B, on the figures observed with white light without blurring, indicate that shifting the phase relations produces little variation in the coloration of the figure. This is to the same degree true of the effects of changing the flash frequency (Tables I, II and III). Under these experimental conditions the phase relations were varied in accordance with Fry's procedure; i.e., any shift in phase was always made so that the absolute lengths of the light and dark phases remained the same.

If, however, the results of conditions under the blurring technique are considered, it is seen that shifting the phase produces rather wide, though not consistent, variations in both the color of the core and the attendant zones. Reduction of boundary sharpness introduces more variability in the subjective colors.

*Inadequacy of the Modulation Explanation.*—While Fry's analyses (**11**, **12**) have made significant and valuable contributions toward showing that the mechanics of the end-organ processes are not adequate for an explanation of the colors perceived with the Benham disc, it is doubtful if the modulation hypothesis is sufficiently comprehensive to deal with the formation of multiple boundaries, the intermittent and steady field effects, the instability of the colors and zones and the long term developmental effects. Certainly these are not readily explained by a "complicated stimulus pattern which involves the stimulation of adjacent areas of the retina with different temporal patterns of intermittent white light" (**12**, p. 464).

The results of this study suggest that concepts of disparate latencies and of modulation of receptor and nerve discharge are inadequate, and that a theory of field articulation in terms of total and partial stimulus gradients is more promising. Such a theory may utilize the concepts of modulation and disparate latencies, but in forms so generalized that they apply not to single receptor cells or nerve fibers but to networks which may very well be structurally nonspecific and capable of supporting a great variety of excitation patterns.

Temporal non-uniformity or intermittence of excitation appears as a *sine qua non* of the Fechner colors and allied transient phenomena. Intermittence of excitation may arise in two distinct ways: (*a*) because of intermittent or variable stimulation, and (*b*) because of variations in the functional efficiency of the receptors and the associated nerve network. These last comprise presumably random metabolic variations in the optic sector which affect the functional efficiency of the visual mechanism. Faint articulation of the visual field occurs when the stimulus field is spatially and temporally uniform. The instability of the color patterns of the physically homogeneous field is probably the most nearly direct evidence for this postulated random variation of the metabolic condition of the visual process. At the same time the fact that relatively simple patterns occur as frequently as they do points to a mechanism of field articulation which needs very little material upon which to operate, and which seems to obey a law of minimum complexity—the Gestalt Law of Prägnanz, or something analogous.

If the temporal uniformity is removed and intermittence of stimulation is added to such a spatially uniform field, the perceptions become enhanced and complicated. Variations of the excitation pattern due to random metabolic variations in the receptor cells and nerve fiber network are somehow magnified because of the intermittent stimulation and are superimposed upon the variable excitation pattern that is due directly to the stimulation intermittence. The resultant variable excitation pattern is comparable in degree to heterogeneity to the excitation patterns of ordinary seeing when the field of vision is physically not homogeneous. Hence there are visual phenomena, although they correspond to no physical reality.

In the case of the investigations where an intermittent figure is seen against an intermittent ground, the boundary is defined by a brightness difference. Since the figure and ground illuminations were physically equal, the figure was visible only when it was to some extent out of phase with the field. Momentarily, then, there is a physical boundary, i.e., a stimulus gradient rising from the dark region to the light region. This stimulus gradient is obliterated when both regions are equally illuminated. Then there is again a momentary physical boundary and a stimulus gradient, but now the stimulus gradient is reversed. Finally this gradient disappears and a new cycle begins. This holds true for all phase relationships except two: one where the figure and ground illuminations are in phase and the figure is invisible; the other where the figure and ground illuminations are in directly opposed phase and the stimulus gradients are periodically reversed without the intervening intervals of figure and ground equality. In this experimental situation, then, the boundary is de-

fined by stimulus gradients that are being continually varied. Now the crux of the matter is that figure-ground segregation takes time and that here not enough time is available to permit complete development of any one of five possibilities: (*a*) homogeneous field, no figure, (*b*) bright figure in a dark ground, (*c*) dark figure in a bright ground, (*d*) a dark ground showing through a hole in the center of a bright region and (*e*) the reverse of (*d*). In any case, the boundary is rendered highly equivocal. This does not mean, however, that it will be lost or even necessarily diminished. Apparently perceptual segregation is obtained in the form of phenomenal boundaries based on hue differences rather than exclusively on brightness differences.

The retinal stimulus gradients, moreover, will not be the same shape under all conditions. Their steepnesses will depend upon the way in which the stimulus light is distributed over certain regions of the retina. The blurring technique may be considered to have the effect of producing a diffuse image of the figure on the retina. Here the stimulus gradient will undoubtedly have a slope less steep than in the case of no blurring. Blurred and unblurred phenomenal contours correspond to stimulus gradients of different degrees of steepness.

The fact that the colors are enhanced by blurring then follows. Making the boundary more indefinite by flattening the stimulus gradient increases the equivocality and calls forth reserve expedients, hue differences, which make for increased figure-ground segregation. Since this effect seems to be independent of the composition of the light, it cannot depend solely on receptor processes.

Multiple boundaries with blurring, too, are thus related to the shapes of the stimulus gradients. Inasmuch as a blurred phenomenal contour corresponds to a flat gradient there would exist a wide zone of indefiniteness and a broad area in which the boundary-forming process could operate.

## Summary

1. A new and more versatile figure-ground technique was used to study certain visual transient phenomena (Fechner-Benham colors).

2. These color patterns may be obtained with intermittent or non-intermittent monochromatic red (no wave length shorter than 650 mμ), and green (spectral centroid 560 mμ) illumination as well as with white light.

3. Under conditions of intermittence reduction of the boundary sharpness of the figure produces a series of unstable chromatic zones (multiple boundaries) around the figure. These zones do not arise at once but take some time to develop.

4. Change of phase relationship between figure and ground illuminations and of intermittence frequency produces greater change in the color patterns with blurred contours than with unblurred contours.

5. Colors may appear in stationary, physically homogeneous, intermittently illuminated fields under each of the conditions of illumination employed.

6. Two theories are briefly considered and a tentative hypothesis discussed. According to the latter, visual transient phenomena are to be interpreted in terms of a general figure-ground segregation process modified by random metabolic variations in the optic sector.

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# OCTAVE GENERALIZATION, PITCH DISCRIMINATION, AND LOUDNESS THRESHOLDS IN THE WHITE RAT

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To the human observer, two tones separated by an octave are very similar. This is not surprising when we are considering ordinary impure tones. The first overtone of a given note is identical with the fundamental of a tone an octave above it, and each overtone in one sound has its counterpart in the other. Thus there is substantial physical identity between the two tones. When we consider relatively pure tones, however, we must look for another explanation. It seems unlikely that the similarity is due to overtones introduced by the cochlear mechanism, since Stevens and Davis (**8**) report no induced second harmonic in man, cat or guinea pig when the pure tone stimulus is less than 50 db. above threshold. There remain at least two other possible explanations: (1) learning and (2) a neural mechanism, such as a spiral localization of frequencies in the cortex, in which frequencies separated by an octave activate adjacent areas. The present experiment was performed to investigate the first of these possibilities. If rats responded similarly to pure tones separated by an octave, it would seem unlikely that the equivalence of these stimuli could be attributed to learning, since rats have had no experience with musical tones.

The most obvious way to answer the question was to train rats to respond to a tone, and then to measure the gradient of generalization to a series of frequencies which include the octave below the positive tone. If the gradient of generalization showed a hump at the octave, indicating greater generalization to this frequency than to intermediate ones, it would mean that the tone and its octave were 'similar' for the rat. Humphreys (**6**) has performed a similar experiment on man, using the psychogalvanic response as the index. He trained to a frequency of 1967 cycles, and found greater generalization to the octave, 984 cycles, than to 1000 cycles. A number of years ago Dr. E. H. Kemp tried this method in an (unreported) exploratory problem. Unfortunately he obtained complete generalization to all frequencies rather than a gradient. It seemed necessary, therefore, to complicate the experiment somewhat, using both punishment and

*Now at Polaroid Corporation.

reward, so that the gradient would be under better control. A simple dumb-bell shaped box was used, consisting of a starting box, electric grid, and food box.

One group of rats was trained to run in the presence of frequencies of 10,000, 8000, 7000, 5000 and 3000 cycles per sec. When the responses to these frequencies were prompt and of uniform latency, the rats were extinguished to all frequencies except 10,000 which was repeatedly reinforced. The resulting gradient of response strength, as measured by latency and frequency of response, made it possible to detect octave generalization. A second group of rats was trained to run during silence, and to inhibit the response when a frequency of 10,000 cycles was present. When the discrimination was stabilized they were tested on the other frequencies, but unfortunately showed such sharp discrimination that no generalization curve was obtained. The results of this group, however, furnish a measure of the accuracy of the rat in pitch discrimination.

To obtain adequate generalization curves it was necessary to present all tones at approximately equal loudness. At the time the experiment was started the only relevant data were those of Henry (4). There was, however, some question whether his curves represented thresholds of hearing or thresholds of localization. It was, therefore, necessary to determine a rough audibility curve for our rats in our apparatus. This was done before the generalization tests were carried out.

## Apparatus [1]

The apparatus consisted of two parts, a discrimination or obstruction box, and a system for producing the relatively pure tones which served as stimuli to be discriminated. The discrimination box had two interchangeable chambers, separated by a chargeable grid. Each chamber could be placed at either the starting or the reward end of the grid. The chambers were 9 in. × 9 in. × 6 in. high, and were constructed of ½ in. galvanized mesh, so that they would not block the auditory stimuli. Each cage had a smoothly-operating door that could be used to keep the rat in the chamber if it was used as a starting box, or out of it (on negative trials) when it served as a reward box. The runway was a tunnel, 8 in. wide, 12 in. long, and 6 in. high, equipped with a gridded floor and glass walls. The floor was charged by a 240 volt transformer through a 50,000 ohm potentiometer. A fixed resistor of 415,000 was in one of the leads to the floor. The usual shocking current ranged between 0.05 and 0.20 milliamperes, varied as necessary.[2]

The auditory stimuli were furnished by a General Radio Co. type 613-B beat frequency oscillator, an amplifier, attenuator, and a Western Electric Co. 555 receiver. The receiver was three in. above the starting chamber. In a check experiment a Clough-Brengle Type OB oscillator and associated equipment were used with the same receiver, to obtain a more pure tone. The apparatus was in a soundproof room. Switches were of the mercury type, to avoid clicks. Any possibility of induced effects from the oscillator to the receiver was minimized by shorting the receiver input as well as breaking the circuit.

[1] A more detailed description of the apparatus, methods and results may be found in: H. R. Blackwell, Masters Thesis, Brown Univ. Library.

[2] This arrangement was suggested by O. H. Mowrer, as one which avoids the variable effect of low-voltage systems, but does not encourage the crouching which is caused by high-voltage, high-resistance systems.

## Animals

Five male albino rats from the laboratory colony were used throughout the experiment. They were litter mates, fairly well inbred, largely from Wistar stock. They were isolated at 70 days, and kept on a single daily feeding of wet mash for a week before training started. Three of the rats (Group I) were trained to run only when a tone was sounding. The other two (Group II) were trained to run on silence. The training of both groups was carried on concurrently, but for clarity we will describe the Procedure and Results of Group I before we make further mention of Group II.

## Procedure, Group I

An animal was placed in the starting box. A tone was turned 'on,' and two sec. later the door was opened. The rat ran out fairly promptly, crossed the grid, and entered the food box, where he received a small portion of wet mash. The door was then closed, the tone turned off, and the boxes were interchanged (*cf.* 3) so that the animal was ready for another trial. After 30 sec. the procedure was repeated for the second trial. On each night 20–30 trials were given.

The training stimuli were 5, 6, 7, 8 and 10 kilocycles, presented in random order. They were approximately 10–20 db. above the rats' threshold (see Results), but their exact value is not certain.

In two sessions all three rats learned to run promptly as soon as the door was opened. At this point the discrimination training was started. On 25 percent of the trials the door was opened without the accompanying tone, and the grid was charged. The rats usually ran directly to the food box despite the shock. Hence it was necessary to close the door to the food box, to avoid reinforcement of this habit. When this change was introduced, the animals ran back to the starting box and tried again in a few seconds. They were allowed to continue these repeated errors for two minutes on each trial. Gradually they learned to make only one crossing per trial and eventually merely to touch the grill. After 735 trials all three rats had learned to respond appropriately to food and shock, but their responses were obviously unrelated to the presence of the tone. It seemed probable that a higher intensity was necessary. On checking the apparatus it was found that the impedances of amplifier and attenuator were poorly matched. When this was corrected, training was continued with stimuli of 30–40 db. above the rat thresholds (as given in Results). All three rats mastered the discrimination completely in 48 trials. The rats were given another 48 trials to stabilize the response thoroughly.

It will be recalled that the tone had preceded the opening of the door by two sec. At the onset of the tone the animals crouched at the door, and ran as soon as it was opened. Thus latency was not a measure of the response to the tone. To make this measure available, the procedure was modified. The starting door was opened in the absence of tone, and the grid charged. On positive trials, at the end of 30 sec. the tone was introduced and the grid shorted. Latency was measured (stopwatch) from the onset of the tone until the animal's nose touched the food. On negative trials the tone was omitted, and the grid kept charged for a full minute. The three animals adapted to this change in five trials, so that they did not run until the tone was started.

Intensive threshold tests were now instituted. These tests were necessary to furnish a basis for choice of equal intensities in the later studies of pitch generalization. The values obtained will be presented under 'Results,' to permit comparison with the data of other workers (which were not published when this experiment was carried out). As preparation for the threshold measurements, the intensity of the training stimuli was gradually decreased over a period of several nights. When the threshold region was approached, the absolute criterion of 'run' vs. 'no-run' broke down. On sub-threshold stimulation the animal occasionally ran after a long latency, and of course found the grid uncharged. This weakened the tone-silence discrimination. Hence an arbitrary limit of three seconds was set. If the animal did not run within three seconds of the onset of the tone, it was considered sub-threshold and the starting door was closed to terminate the trial. This value was chosen because it represented a break in the distribution of latencies. Over a wide range of intensities at all frequencies the rats responded consistently with a latency of 2–3 sec. But a decrease of 2.5 db. below a critical intensity for each frequency varied latency as much as 10 sec.

Threshold values were obtained on each of four successive nights for each rat. Each frequency was tested in turn at the same clearly supra-threshold value, and the latency of response

recorded by stopwatch. The intensity was then reduced by a 2.5 db., and each frequency was tested at that level. This was continued until all frequencies were sub-threshold. The thresholds for each frequency were then verified by tests at threshold, 2.5 db. above threshold, and 2.5 below threshold. If serious discrepancies were found, the tests were repeated. One advantage of this method is that it yields response latencies for a fairly wide range of intensities at each frequency.

The threshold values were determined for the four training frequencies (5, 7, 8 and 10 kc.) and also for two new ones (3 and 2 kc.). Generalization was immediate to those two new frequencies.

After thresholds were obtained, the rats were subjected to extinction of responses to all but 10 kc., in order to measure generalization gradients of extinction. During one session (48 trials) the animals were allowed to cross the uncharged grid and enter the food compartment on every trial. Food was present only when the 10 kc. frequency was sounding. This procedure did not lead to extinction. Therefore the grid was lightly charged on negative tones. During the first session in which shock was used the response to certain frequencies was inhibited, so that the latencies increased markedly and showed a gradient. Generalization gradients for this night and for five more were measured in terms of latency and frequency of response. In determining frequency, an arbitrary limit of 15 sec. was set. If the animal had not run within 15 sec. of the onset of the tone, the trial was terminated and considered a negative one.

During each extinction session the positive tone (10 kc.), was presented 24 times. Each of the negative tones (8, 7, 5, and 3 kc.) was presented six times. The intensity of all tones was 15 db. above the threshold values already obtained.

Only two of the three rats completed the extinction series. The other rat was discarded for he soon started to run as soon as the door was opened, long before the tone was presented. Whether this behavior should be called 'regression,' 'inhibition of the inhibition of delay,' or something else, does not concern us here.

## Results and Discussion, Group I

### *Thresholds*

Table I presents the audibility thresholds for frequencies of 2, 3, 5, 7, 8 and 10 kc., for each of three rats. They are expressed in

TABLE I

Thresholds for Rat and Man, Expressed in Decibels Below Five Volts

| Rat Designation | Frequency (cycles/second) | | | | | |
|---|---|---|---|---|---|---|
| | 2000 | 3000 | 5000 | 7000 | 8000 | 10,000 |
| 1 | 32.5 | 32.5 | 35.0 | 35.0 | 37.5 | 37.5 |
| 2 | 32.5 | 35.0 | 37.5 | 37.5 | 37.5 | 40.0 |
| 3 | 32.5 | 35.0 | 37.5 | 40.0 | 40.0 | 42.5 |
| Average (rat) | 32.5 | 34.2 | 36.6 | 37.5 | 38.3 | 40.0 |
| Average (man) | 76.2 | 74.3 | 68.6 | 61.7 | 55.6 | 50.0 |
| Man—rat | 43.7 | 40.1 | 32.0 | 24.2 | 17.3 | 10.0 |

terms of decibels below 5 volts on our apparatus. The same table also presents average thresholds for 10 apparently normal human ears, measured in the same position as the starting box. The human thresholds make it possible to compare our results with those of other workers. In the last line of Table I the average rat thresholds

are given in terms of decibels above human thresholds. In Fig. 1 these values are plotted (Line B) above the accurate human thresholds obtained by Sivian and White, as presented in Stevens and Davis (8). Fig. 1 also included the data obtained on the rat by Henry (4), Gould and Morgan (2) and Eccher (1). Of these data, only those of Henry had been published before ours were obtained. Through the kindness of Dr. Morgan, we had his data before they were published. Eccher's results were unknown to us until after ours were obtained. The similarity in slope and absolute values of three of the four curves is surprising in view of the difficulties involved in control of auditory stimulation. Henry's curve is clearly different from the other three. It was obtained from a multiple discrimination apparatus, in which

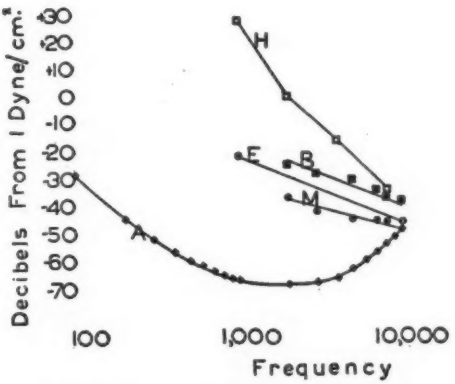


FIG. 1. Lower thresholds for the rat. Curve A represents the data of Sivian and White, on the human ear. It furnishes reference points for plotting the rat thresholds, as determined by: M—Gould and Morgan; E—Eccher; B—Blackwell and Schlosberg; H—Henry. Curves M, E and B were obtained by roughly similar techniques.

the rat was forced to discriminate between a tone-filled and a silent alley. In addition to the possible complications caused by echos, it is possible that the type of discrimination required was more difficult for the rat. In his experiment the rat had to localize the tone. In contrast, the three similar curves were obtained by methods that clearly required a response to the onset of a tone. Gould and Morgan used a circular runway with chargeable segments. The rat escaped shock if he moved a distance of one segment within two sec. of the onset of the tone. Eccher required his rats to jump from one section of the cage to another. Our method was somewhat more complex, involving both punishment and reward. The greater complexity was deliberately introduced to make it possible to cut down complete generalization by using balanced punishment and reward. This

greater complexity would account for the fact that our curve runs 5 db. above Eccher's and 10 db. above that of Gould and Morgan—if we assume that the difference is a true one, and not due to differences in animals, auditory equipment, and reference level. Thus on both logical and empirical grounds, the three parallel curves seem to represent the rats' intensive threshold. It is worth noting that all the results indicate the increasing insensitivity of the rat to frequencies below 10 kc. Gould and Morgan indicated that sensitivity increases to at least 40 kc.

## Generalization

After the original training, there was marked generalization along both the intensity and frequency dimensions. The average latent period of the response remained between 2.6 and 2.8 sec. over a range of from 10 to 35 db. above threshold. The latencies were apparently unaffected by the frequency of the test tone, even when the two new tones (2 and 3 kc.) were introduced. This lack of discrimination might have been expected, for tones of varying pitch and loudness were used during the training. It was necessary to use differential reinforcement and punishment to obtain any generalization gradient.

TABLE II

Strength of response to test frequencies in the first experiment. Each entry represents the average for six trials for each of two rats, except those under 10,000, which are based on 24 trials for each rat.

| Night | Response Measure | Stimulus, in cycles/sec. | | | | |
|---|---|---|---|---|---|---|
| | | 10,000 | 8000 | 7000 | 5000 | 3000 |
| A | Percentage Positive Response | 94 | 67 | 50 | 75 | 50 |
| | Log. Median Latency | .42 | .73 | .83 | .46 | .97 |
| B | Percentage Positive Response | 92 | 54 | 67 | 47 | 53 |
| | Log. Median Latency | .45 | .83 | .74 | 1.09 | 1.04 |
| C | Percentage Positive Response | 94 | 58 | 50 | 58 | 42 |
| | Log. Median Latency | .45 | 1.12 | 1.03 | 1.14 | 1.14 |
| D | Percentage Positive Response | 99 | 73 | 60 | 73 | 53 |
| | Log. Median Latency | .60 | .77 | .83 | .96 | 1.12 |
| E | Percentage Positive Response | 92 | 67 | 58 | 75 | 50 |
| | Log. Median Latency | .22 | .86 | .88 | .90 | 1.10 |
| F | Percentage Positive Response | 73 | 33 | 42 | 67 | 33 |
| | Log. Median Latency | .50 | 1.09 | 1.09 | .95 | 1.18 |
| Aver. | Percentage Positive Response | 91 | 59 | 55 | 66 | 47 |
| | Log. Median Latency | .44 | .90 | .90 | .92 | 1.09 |

Table II shows the effect of continuing reinforcement of responses to 10 kc., while responses to other frequencies were unrewarded and punished. Results are given in terms of frequency of response and of the logarithm of the median latency for each frequency on each day of testing. Twenty-four measurements from each of two rats were used for the daily values at 10 kc., and one quarter of that number at each of the other frequencies. The data from the two rats were highly similar, so that averaging merely stabilized the values.

The averages obtained from the six days have been plotted in Fig. 2. The solid circles represent the frequency of response data,

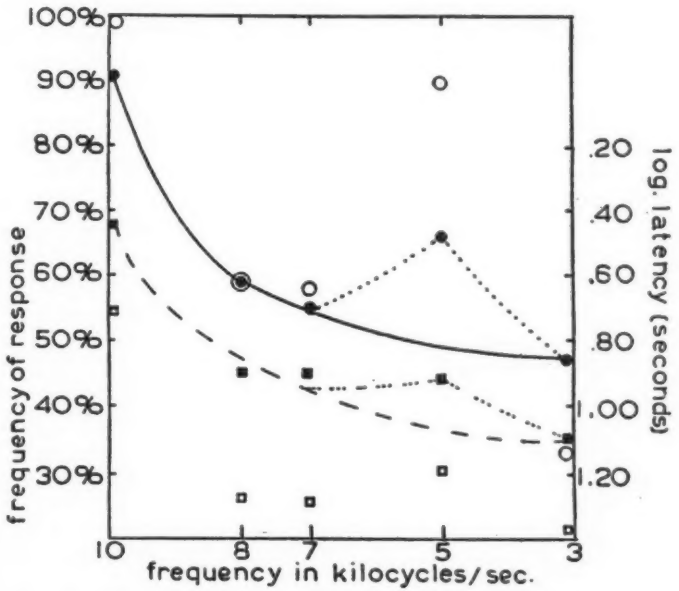


FIG. 2. Extent of generalization during extinction. The response to 10,000~ was continuously reinforced. The results of the main experiment are plotted in black dots or squares, while those of the check experiment are indicated by hollow figures. Circles are used for percentages of trials on which responses occurred, and should be referred to the left hand ordinate. Squares represent averages of median log. latencies, and may be read from the right hand ordinate. The heavy lines suggest the probable shape of the gradient if there were no octave generalization. The dotted lines indicate the effects of the octave.

and should be referred to the left hand ordinate. The log. latencies have been plotted as solid squares, and should be referred to the right hand ordinate. It will be noticed that this ordinate has been inverted, since strength of response is a negative function of latency.

The hollow circles and squares present the results of a check experiment on the same animals (see below). Heavy curves have been drawn to represent the probable course of the gradient of generalization if there were no octave upswing. It will be seen that the values for the octave below the reinforced tone lie above the expected values. These points have been connected to the neighboring ones by dotted lines to aid in reading the graph. Neither of the curves or their appendages is intended to represent the exact shape of the actual gradients. Extended measurement with intermediate frequencies would be necessary to determine the form of the gradients. But the rough constructions in the figure indicate the octave upswing more clearly than do the tabulated averages.

The occurrence of octave generalization is also indicated by the daily progress of extinction. An examination of the daily values, particularly those giving percentages of responses, shows that the course of extinction was irregular. The first day that shock was used yielded a smooth gradient, with marked octave generalization. In fact the percentage of response curve, if plotted, would look quite like the average curve of Fig. 2. The percentage values were closely paralleled by those for latency. But on the second day the strength of response to 5 kc. was greatly depressed. By the third day the gradient (as measured by percentage of response) was similar to that of the first day, and changed little on the fourth and fifth day. On the sixth and last day the discrimination showed signs of breaking down. The response to the positive frequency (10 kc.) dropped in frequency to 73 percent, whereas it had stayed above 90 percent during the first five sessions. The response to 8 kc. fell with that to 10 kc. but the octave generalization was very pronounced. Testing was discontinued after this day. In summary, the octave generalization that shows so clearly in the average curves was also found on five out of six days.

It is even possible to show that the peculiar results of the second day are themselves a result of octave generalization. On the first day the animals had run 75 percent of the trials on 5 kc., and 67 percent on 8 kc. The strength of the response to 5 kc. must have been due to octave generalization. All of these responses were punished. This set up considerable extinction for these two frequencies. On the next day these frequencies showed the effects of this extinction, which depressed the response strengths below the values expected from the generalization gradient. By the third day the continued testing of the unreinforced frequencies had established a generalized inhibition, against which the gradient of response strength from the positive (10 kc.) stimulus showed up in its normal form.

A similar day-by-day analysis has been made of the latencies of each of the rats. On the first day of extinction both rats showed shorter latent periods to the octave, 5 kc., than to either of the neighboring percentages. On the second day all latencies went up as a result of the punishment. Further, since the animals failed to respond on about a half of the presentations of the negative stimuli, it was impossible to compute mean log. latencies.[3] This difficulty was partially overcome by using median log. latency instead. Of course the medians are not stable with only six trials at each frequency each day, but even this rough measure was surprisingly sensitive. The excess extinction on the first day showed its effect on latency through the fourth day. Both animals again showed some octave generalization in their latency curves on the fifth and sixth days, but it was still far from pronounced. Apparently latency showed the effects of extinction much more than did frequency of response.

## Check Experiment

In view of the great sensitivity of the rat to a frequency of 10 kc., the question of possible harmonics in our sound source must be considered. The input to the voice coil was analyzed with a General Radio Co. Wave Analyzer.[4] At levels used in training, the second harmonic of the 5 kc. tone was almost half as strong as the fundamental. At the intensity levels used in threshold measurements the second harmonic was only 7 percent, or about 25 db. below the fundamental. Since the tests for generalization utilized a 5 kc. tone that was 10–15 db. above threshold, and since the threshold for 10 kc. was almost 5 db. below that for 5 kc., there was a possibility that the octave generalization was more apparent than real. The daily changes in the form of the generalization gradient make such an explanation somewhat improbable, however. The sudden drop in frequency of response to 5 kc. on the second night, with no change in the responsiveness to 10 kc., would imply discrimination between these two frequencies. But to make certain that the octave generalization was not an artifact, the generalization data were repeated on a new instrument four months later. As noted under 'Apparatus,' a Clough-Brengle oscillator with matched amplifier and attenuator was attached to the speaker. Measurement showed that the second harmonic at any frequency or intensity never exceeded 0.5 percent of the fundamental. The two animals were retrained to the tone-

[3] See (7) for the advantages of this measure.

[4] We wish to thank Dr. L. W. Labaw of the Brown Department of Physics for making these and later measurements. We are also grateful to Mr. Lloyd Beck of the Psychology Department for assistance with the apparatus.

silence discrimination for 125 trials, which was 50 more than they needed to relearn it. They were then extinguished to all frequencies except 10 kc., as in the original experiment, except that they were allowed 30 sec., instead of 15 sec., to run. One rat showed complete extinction to all but the reinforced tone on the second night. In Table III his results for the first night are presented. Data from

TABLE III

RESULTS OF THE 'CHECK EXPERIMENT'

| Night and Rat | Response Measure | Stimulus, in cycles/sec. | | | | |
|---|---|---|---|---|---|---|
| | | 10,000 | 8000 | 7000 | 5000 | 3000 |
| N-1, R-1 | Percentage Positive Response | 95 | 67 | 33 | 84 | 50 |
| | Log. Median Latency | .99 | 1.27 | 1.48 | 1.02 | 1.35 |
| N-1, R-2 | Percentage Positive Response | 100 | 67 | 100 | 100 | 50 |
| | Log. Median Latency | .53 | 1.23 | 1.16 | 1.07 | 1.21 |
| N-2, R-2 | Percentage Positive Response | 100 | 100 | 50 | 100 | 0 |
| | Log. Median Latency | .54 | 1.10 | 1.23 | 1.35 | 1.44 |
| N-3, R-2 | Percentage Positive Response | 100 | 0 | 50 | 75 | 33 |
| | Log. Median Latency | .80 | 1.48 | 1.26 | 1.30 | 1.48 |
| Average | Percentage Positive Response | 99 | 59 | 58 | 90 | 33 |
| | Log. Median Latency | .72 | 1.27 | 1.28 | 1.19 | 1.37 |

three nights were obtained from the second animal and are presented in the same table. The averages of these four sessions are plotted in Fig. 2 as hollow figures. The values obtained from both animals on the check experiment, although somewhat irregular, confirm those obtained in the first experiment. If there is any difference between the two sets of data, it is in the direction of more pronounced octave generalization in the check experiment in which the second harmonic of the 5 kc. frequency was negligible. The greater octave generalization shows in both latency and frequency values. It is thus apparent that octave generalization in the rat is a genuine auditory effect, and not an artifact. In extent it is probably not as great as Humphreys (**6**) found in man, but the comparison is difficult to make.

The writers have been unable to find any purely auditory phenomena which would explain octave generalization. Stevens and Davis (**8**) report that the 'subjective' or 'aural' second harmonic in man is absent at less than 50 db. above threshold. Our stimuli were well below that value. Unless the rat ear differs markedly from that of man, the explanation of octave generalization must be in terms of central organization of the auditory pathways. It is improbable that octave generalization is the result of previous learn-

ing. The rat had heard sounds in its environment during its normal life. If these sounds had been rich in overtones, there might have been a cross-conditioning effect between the fundamental and its overtones, so that 5000 and 10,000 cycles, for example, would be equivalent through learning. This explanation, however, would work better for generalization from a stimulus of 5 kc. to one of 10 kc., than in the reverse direction we have studied. Further, we suspect that tones of 5 and 10 kc. have played very little part in the previous life history of our rats. It therefore seems likely that the octave generalization we have found in the rat is dependent upon some aspects of the auditory mechanism, either peripheral or central, rather than upon learning.

### The Shape of the Generalization Gradient

Schlosberg and Solomon (**7**) have argued that a gradient of primary generalization should yield a straight line, if plotted in the proper units. The gradients we have found here are obviously concave, even though we used log. latency, a measure which they favored. If our baseline had been a logarithmic scale of frequencies, which is more reasonable than the linear one we have used, the curvature of the gradient would have been even more pronounced. Thus our results seem to refute the contention of Schlosberg and Solomon. But the contradiction is more apparent than real. The gradients we have reported here are gradients of response strength, superimposed on the primary generalization gradients. Punishment was used at four points along the continuum, which would tend to depress the strength of response more or less uniformly at these four positions. There should therefore be a sharp drop in response strength between the positive stimulus (10 kc.) and the nearest negative one (8 kc.), and a slower fall thereafter, except for the upturn at the octave. This is exactly what we obtained. It is possible that the same line of reasoning would explain the slightly concave gradients reported by Hovland (**5**) and Humphreys (**6**) for conditioned G.S.R. in man.

### Group II

As noted under 'Animals,' two additional rats were trained to run on silence. That is, they had to learn to inhibit the response to the opening of the door when the tone of 10 kc. was present, but were free to make a rewarded run in its absence. No other frequencies were used during the training. Otherwise the animals were carried through a program of training similar to that used with Group I. They were trained in this fashion in the hope that when learning had been completed, tests with other frequencies would yield a generalization curve directly, without an extinction series.

These two rats were tested with the other frequencies at the same time that Group I was given threshold tests. There was no generalization; the rats inhibited response on 10 kc., but reacted to 8, 7, 6 and 5 kc. as to silence. At this time no data on pitch discrimination in the rat were available in the literature, so it seemed worthwhile to push the discrimination further. Training was continued by the method of contrasts, punishing responses to 10 kc., and rewarding those to 8 kc. At first this led to a breakdown of the discrimination, so that the rat ran on 10 kc. as well as on 8 kc. After several days the discrimination was re-established and pushed as far as possible. One rat eventually discriminated between 10 kc. and 9 kc., the other between 10 kc. and 8.5 kc. A criterion of 85 percent was used for these thresholds. These values are not much below those recently reported by Eccher (1). He was able to train rats to discriminate between 10 kc. and 9.4 kc. The intensity level was about the same in both experiments, but the method of presentation was radically different. Eccher used a shift in frequency of an intermittent tone, so arranged that the two tones to be discriminated were separated by only 1.5 seconds. In the present experiment there was an interval of 30 sec. between successive trials, and thus between successive tones. The ability of the rat to make such accurate tonal discrimination when the stimuli are separated by 30 sec. suggests that there may be absolute localization of 'pitch' in the cortex. Otherwise the 'stimulus trace' of a tone lasts a surprisingly long time.

## Summary and Conclusions

1. Rats were trained to run from one compartment across a grid to a food compartment only when tones of 10, 8, 7, 5, 3, or 2 kc. were sounded. Audibility thresholds obtained by this method are very similar to those obtained by Gould and Morgan and by Eccher.

2. In terms of latency the rats showed complete intensity generalization through a range of 15–35 db. above threshold. There was a sharp increase in latency at the threshold.

3. The response to 10 kc. was continually reinforced while that to the other frequencies was extinguished. The gradient of response strength during extinction showed a hump at 5 kc., indicating octave generalization. The hump was found in both frequency of response and in log. latency data. A check experiment with very pure tones yielded even more pronounced octave generalization.

4. Two other rats were trained to run only during silence, and to inhibit the response in the presence of 10 kc. When tested with the other frequencies, these animals showed complete discrimination between 10 and 8 kc. On further training one rat discriminated 10 kc.

vs. 9 kc. and the other, 10 kc. vs. 8.5 kc., despite the fact that the tones were separated by 30 sec. during testing.

(Manuscript received October 19, 1943)

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# RETROACTIVE INHIBITION AS A FUNCTION OF DEGREE OF ASSOCIATION OF ORIGINAL AND INTERPOLATED ACTIVITIES

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In a recent summary of the status of research in the field of retroactive inhibition, McGeoch (**8**, p. 461 ff.) has listed as one of its main determinants the degree of similarity between original and interpolated activities. He makes a dimensional analysis of the general factor of similarity showing that it may involve form, meaning, set, etc. In so doing he has followed the practice adopted by nearly all workers in the field. The chief exception is Gibson (**4**) and her successors, who have maintained that similarity is merely a special case of generalization as obtained in conditioning experiments. Cofer and Foley (**2**) have extended the concept of generalization greatly until under the name of mediated generalization it includes any learned connection between two stimuli.

It is the purpose of the present experiment to show that neither similarity nor generalization in its original sense are broad enough terms to cover all the relationships between original and interpolated activities which will affect the amount of retroactive inhibition. The particular relationship chosen for investigation here is the frequency of association between two common words as determined by the percentage of their appearance together in a free association test. That is, it was predicted that if stimulus words in a paired-associates list were connected in the past experience of the *S* with stimulus words in an interpolated list, they would tend to evoke the interpolated responses in recall, causing more associative interference or retroactive inhibition than if the stimulus words were not so connected.

## PROCEDURE

The technique throughout was that of a standard experiment in paired-associate learning (**11**). Lists of 12 pairs of words were prepared and presented on a mechanically-driven, Hull-type memory drum in three different counterbalanced orders at the rate of one every four sec. During the first two sec. the stimulus word only was exposed and the *S* was to anticipate the response word before it appeared for its two-sec. exposure. There was an eight-sec. rest between one presentation of the list and the next.

[1] The junior author is responsible for running the *S*s, the senior author for formulating the problem and interpreting the results.

There were three lists in all. The first was used by all *Ss* for original learning. The other two were used in interpolated learning and differed only in whether the stimulus words were related to the stimulus words in the first list or not. If the first list is designated by the symbol A—B, the interpolated lists stood in the relation A′—D, and C—D. The relatedness of the stimulus members of the pairs in the two lists was based on the frequency of free association as reported in O'Connor's tables. Table I presents the actual percent association out of 2000

TABLE I

FREQUENCY OF ASSOCIATION BETWEEN STIMULUS WORDS IN ORIGINAL AND RELATED INTERPOLATED LISTS IN TERMS OF PERCENT OCCURRENCE IN 2000 FREE ASSOCIATIONS, (14, p. 227 ff.)

| Original S-Words A | Related S-Words A′ | Percent A and A′ Associated | Unrelated S-Words C |
|---|---|---|---|
| Priest | Church | 18.65 | Chair* |
| Bread | Butter | 16.15 | Meat |
| Thirsty | Water | 30.70 | Storm |
| Blue | Sky | 20.85 | Roof |
| Dark | Night | 19.15 | Month |
| Spider | Web | 26.40 | Bell |
| Hammer | Nail | 25.05 | Chisel |
| Sweet | Sugar | 19.05 | Hair |
| Loud | Noise | 18.30 | Foot |
| Green | Grass | 26.05 | Road |
| Scissors | Cut | 41.45 | Send |
| Carpet | Floor | 25.05 | House |

*The unrelated stimulus words were chosen with the idea of keeping them as comparable to the related stimulus words (A′) as possible in other respects such as degree of difficulty, part of speech, familiarity, number of syllables, etc.

responses (14, p. 227 ff.) of each of the 12 pairs of related stimulus words. The Kent-Rosanoff stimulus words used by O'Connor were the stimulus words in the initial list A—B, and the frequently associated response became the stimulus word in the interpolated list A′—B. The stimulus words in the unrelated interpolated list were either other stimulus words in the Kent-Rosanoff list or other words obviously having a low association value. The response words in all three lists were three-letter nouns from Melton's materials (11). All other intra- or inter-list connections on the basis of formal or meaningful similarity between stimulus words and/or response were eliminated so far as possible following the usual rules (*cf.* 11, 15).

The *Ss* were 30 Wesleyan undergraduates all of whom had had so much previous practice in learning this type of list in other experiments (at least four previous sessions each) that further practice was considered unnecessary. All of them learned the first list A—B to the criterion of 9 out of 12 correct anticipations; half of them then learned list A′—D, and the other half list C—D, to the same criterion of 9 in 12 correct responses; after a three-min. rest all returned to the original list and relearned it to a criterion of two perfect trials in succession. They all received the standard instructions given for paired associate learning to be found in Melton (11). They were additionally motivated by the offer of a $5.00 prize which was to go to the person who could reach the criteria in the fewest trials.

## RESULTS

Table II presents the original and interpolated learning scores for the two conditions. Apparently the two groups of *Ss* were satisfactorily equated in learning ability, as is shown both by the number of correct responses on the critical trials and by the number of trials to reach the criterion of 9 out of 12 correct responses. It took the

TABLE II

AVERAGE ORIGINAL AND INTERPOLATED LEARNING SCORES

| Condition | N | Original Learning | | Interpolated Learning | |
|---|---|---|---|---|---|
| | | Trials to 9/12 | No. Right Crit. Trial | Trials to 9/12 | No. Right Crit. Trial |
| Unrelated S-words | 15 | 5.40 | 10.20 | 4.47 | 10.27 |
| $\sigma$ mean | | .51 | .20 | .40 | .20 |
| Related S-words | 15 | 5.47 | 10.27 | 5.13 | 10.27 |
| $\sigma$ mean | | .59 | .22 | .50 | .20 |

related group somewhat longer to reach the criterion in interpolated learning, but the difference (.66 trials) is not significant (critical ratio = 1.03, $P < .16$). This retardation is to be expected if there is any associative interference between the two lists. A more sensitive measure of such interference is to be found in the average number of correct responses on the second or third interpolated learning trials in the two groups. In the unrelated condition the average score on the second IL [2] trial was 4.40 correct responses, in the related 3.33 correct responses, a difference which, though it too is unreliable (C.R. = 1.30, $P < .10$), indicates that some associative interference in IL may have been present in the related group that was not present in the unrelated group.

TABLE III

AVERAGE RELEARNING SCORES

| Condition | Recall 1 | Recall 2 | Recall 3 | Trials to Two Perfect |
|---|---|---|---|---|
| Unrelated S-words | 7.93 | 10.07 | 10.60 | 6.00 |
| $\sigma$ mean | .50 | .31 | .44 | .73 |
| Related S-words | 4.87 | 8.47 | 10.07 | 6.60 |
| $\sigma$ mean | .48 | .43 | .36 | .67 |
| Difference | 3.06 | 1.60 | .53 | .60 |
| $\sigma$ diff. | .69 | .54 | .57 | 1.29 |
| Critical ratio | 4.44 | 2.96 | .93 | .47 |

Table III presents the mean number of correct responses on the first three recall trials and the average number of trials to reach the criterion of two perfect recitations in succession. The critical ratios of the differences on the first and second recall trials show clearly that the interpolated learning was definitely more harmful when it

[2] Throughout this paper in keeping with recent practice (12, 13, 15) the symbols OL, IL, and RL will be used to stand for original learning, interpolated learning, and relearning. RI and RC stand for retroactive inhibition and recall respectively.

was related through past association to OL than when unrelated. The interference disappeared almost entirely by the third recall trial, however, and there is practically no evidence of it in the relearning scores. As in other experiments (**9**, **12**) retroactive inhibition was present in large amounts but was exceedingly transitory. The data in Table II support the original hypothesis unequivocally. Using stimulus words in the interpolated list which have been frequently associated with the stimulus words in the original list *does* increase retroactive inhibition in the immediate recall of the original list, but has no reliable effect beyond the second recall trial.

Other studies (**9**, **10**, **12**, **15**) have found the analysis of overt intrusions from one list to the other to be a very useful method of gaining insight into the actual interferences taking place. Table IV

TABLE IV

NUMBER OF EXTRA-, INTER-, AND INTRA-LIST INTRUSIONS IN ORIGINAL LEARNING, INTERPOLATED LEARNING, AND RELEARNING

| Condition | Original Learning | Interpolated Learning | | | | Relearning | | | |
|---|---|---|---|---|---|---|---|---|---|
| | Total | Extra | Inter | Intra | Total | Extra | Inter | Intra | Total |
| Unrelated | 80 | 4 | 4 | 25 | 33 | 2 | 6 | 31 | 39 |
| Related | 71 | 5 | 6 | 37 | 48 | 4 | 21 | 38 | 63 |
| $\chi^2$ | .54 | .11 | .40 | 2.32 | 2.78 | .67 | 8.33 | .71 | 5.65 |

$\chi^2 = 3.84$ at 5 percent level, 6.64 at 1 percent level of significance.

presents such an analysis extended to include all cases of a word given in place of the correct one. The source of these intruding responses may be the list itself (intra-list), another list in the experimental procedure (inter-list), or some material completely foreign to the experiment proper (extra-list). The most important intrusions —and those dealt with exclusively by other investigators (**12**, **15**)— are inter-list because they reflect directly associative interference.

In IL the total number of inter-list intrusions was small and did not differ for the two groups. In relearning there were reliably more such intrusions for the related condition ($\chi^2 = 8.33$). Thirteen of the 21 instances involved the related pairs. For example, in OL there was the pair, *Green-Sum*. Its related pair in IL was *Grass-Ark*. When in recalling the original list a subject responded to the stimulus word *Green* with the word *Ark*, it was taken as *prima facie* evidence that it was the relatedness of the stimulus words, *Green-Grass*, which had produced the intrusion.[3] There were two more

[3] Six related pairs provided all 13 intrusions. The associated stimulus words involved were: *Priest-Church, Bread-Butter, Dark-Night, Sweet-Sugar, Loud-Noise, Green-Grass.* Their average

instances in which the first list stimulus evoked the second list related stimulus word rather than its associated response. Thus there were in the related condition just six inter-list intrusions not based on relatedness—exactly the same number as was found in the unrelated condition. Furthermore, eight of the inter-list intrusions appeared on the first recall trial, eight on the second, and four on the third, or 20 out of 21 on the first three trials. Both these facts support the inference that a large part of the increase in retroactive inhibition which was localized in these trials was due to associative interference between the two lists based on the relatedness of the stimulus members of the pairs.

Table IV presents a number of other points of interest. It should be noted first that it is legitimate to compare the total number of intrusions in OL, IL, and RL, because fortunately the number of trials spent on the average in each part of the learning was about the same. That is, in relearning the two criterial trials must be subtracted from the averages in Table II since no intrusions could by definition occur on them. And in OL and IL one trial should be subtracted from each average, since no intrusion could occur the first time through the list. This means that about four trials were spent by both groups on each part of the learning procedure and that therefore the opportunity for the appearance of intrusions in all three parts was approximately equal.

It can therefore be concluded that (*a*) there were reliably more intrusions in OL than in IL for both groups ($\chi^2 = 19.55$ and 4.45) and than in RL for the unrelated group ($\chi^2 = 14.13$), (*b*) there was a greater total number of intrusions in RL for the related group, a difference which appears to be due chiefly to the difference in inter-list intrusions, (*c*) there was some unreliable evidence that increasing the inter-list intrusions increased intra-list intrusions, (*d*) there were reliably more inter-list intrusions for the related condition in RL than in IL ($\chi^2 = 8.33$), and (*e*) there were consistently more intra- than inter-list intrusions. The four chi-squares comparing the frequency of these two types of intrusions in IL and RL add up to a total of 59.35 which is well beyond the one percent level of significance with three degrees of freedom. To these facts may be added two others of some significance. None of the inter-list intrusions in IL in the related condition were based on the relatedness of the stimulus members of the pairs. And very few of any of the intrusions were stimulus words in either list. Apparently there was a distinction in

association value (*cf.* Table I) was 19.56 percent, that of the six not yielding intrusions, 28.25 percent, a difference which is the reverse of what would be expected unless stronger connections may be rejected more readily as wrong and may therefore not be given as overt (but rather as covert) intrusions, as Thune and Underwood (15) have argued. All of these associated stimulus words gave two intrusions except *Bread-Butter*, which provided three.

the minds of the *Ss* between stimulus and response terms of the paired associates sufficient to prevent many intrusions of the former. Further evidence for delimitation of the word area from which associates are given lies in the fact that so very few extra-list intrusions appeared.

## Discussion

As predicted, the interpolation of a list of paired associates in which the stimulus members of the pairs were related in past experience to the stimulus members of the pairs in the original list caused much more interference in recall than did interpolation of an unrelated list. Such a result, while clearly a case of retroactive inhibition, does not fit readily into the usual conceptions of RI as being caused by similarity or generalization between the two activities. A pair of stimulus words like *Spider-Web* or *Green-Grass* or *Thirsty-Water* are not similar in meaning or form nor are they sufficiently indiscriminable to permit primary generalization such as Gibson got between two forms that were difficult to distinguish (**5**).

There remains the possibility that the relationship discovered to be of importance here in producing RI could be subsumed under the heading of mediated generalization. This is clearly the solution Cofer and Foley would adopt, as they have listed (**2**, p. 530–531) a number of "formal gradients, or formal dimensions along which generalization may be expected to occur" (such as attributive-substance, cause-effect, etc.). All the present pairs of words would fit one or more of these formal dimensions. But the authors do not explain in any detail just how these 'gradients' are set up. There is an obvious similarity between homophone gradients and the sensory dimensions which produce generalization in conditioning experiments. Both involve a certain indiscriminability among stimuli. Mediated generalization, on the other hand, is said to be caused by the conditioning of any two or more stimuli to the same response (*cf.* Hilgard and Marquis, **6**, p. 230). But it is difficult in the present instance to conceive of what is stimulus and what response. Properly speaking, *Green* is the stimulus to which the response *Grass* has become associated in the past experience of the *S*. To maintain that they are both stimuli which have been associated with some other response of speculative origin is logically possible but requires some complex *ad hoc* assumptions.[4]

[4] Actually there is no need even in sensory pre-conditioning experiments like Brogden's (1) to assume that there is a mediating response involved. When two stimuli (light and bell, for instance) are constantly presented together they may produce a characteristic neural interaction effect as Hull maintains (Postulate 2, 7, p. 47) and this stimulus pattern may be the real basis for the generalization, so that either may evoke a response learned to the other. A similar interaction effect is possible, though less likely here.

There is another more important reason why the concept of generalization does not fit these data very well. If *Green* and *Grass* are really stimuli which become equivalent through some neural interaction effect or through conditioning to the same response, they ought to be confused equally often for each other. But the fact is that whereas *Green* will often give rise to *Grass*, the reverse is not true: *Grass* will seldom give rise to the word *Green*.[5] One could confidently predict that if the list used first in the present experiment were exchanged with the one used second there would be a great deal less inter-list interference. In short, this is not a case of words being used interchangeably as if they were synonyms or equivalent stimuli on the same dimension, but of words being connected *in one direction only*. Rather than stretch the concept of sensory generalization to include such a case it seems better to include both under a still broader principle.

Such a principle could be formulated as follows: Retroactive inhibition is a function of learned or unlearned connections between the original and interpolated activities. Under learned connections would be subsumed all cases of meaningful similarity and associations acquired in previous experience. Under unlearned connections would be subsumed the perceptual or sensory indiscriminability found in Gibson's experiments with nonsense figures (**5**), Foley and Cofer's work with homophone gradients (**3**), and Melton and Irwin's study (**12**) involving formal similarity or partial identity of nonsense syllables.

*Analysis of Intrusions.*—The term 'intrusion' has been broadened somewhat in the present paper to include any word which is substituted for a correct response. Previously it had applied only to inter-list intrusions (**12, 15**). The inclusion of intra-list and extra-list intrusions in the analysis supplies information on other possibly important factors such as the tendency of certain lists to provoke guessing, the proportion of inter-list to total intrusions, changes in intra-list intrusions accompanying changes in the number of inter-list intrusions, etc.

The present data indicate that there is a considerable drop in the total number of intrusions from original to interpolated learning, even though the opportunity for the evocation of intrusions is equal. There are several possible explanations of this fact. The *S*s may guess more early in a session and grow more cautious as learning proceeds. Or the first list may have evoked more intrusions because of some peculiarity in its makeup. Or the first list may have inhibited the learning of the second sufficiently to decrease the number

[5] This is also true of synonyms. *Crafty* is more similar to *Cunning* than *Cunning* is to *Crafty* because *Cunning* has two meanings.

of intrusions. Decision between these alternatives will have to wait on further experimentation. One fact is clear, however: the total number of intrusions is not an index of the number of trials it will take to learn a list. Even though the number of intrusions in OL was much greater than in IL, the number of trials to reach the same criterion was about equal in both instances.

The main fact shown by the analysis of intrusions is that there are reliably more inter-list intrusions in the case of the related stimulus words in relearning. All but one of these 21 intrusions appeared in the first three recall trials, a fact which suggests strongly that the retroactive inhibition obtained on these trials was caused in part at least by overt inter-list intrusions. Since 13 of the 21 intrusions were responses associated in interpolated learning with stimulus terms related in past experience to those evoking them, there seems little doubt that associative or reproductive interference is a major factor behind the increase in retroactive inhibition obtained.

It is of considerable interest that there were only six inter-list intrusions in the interpolated learning of the related list, only two more than for the unrelated list and reliably fewer than in relearning despite the fact that opportunity for intrusions was approximately the same. This discrepancy between the inter-list intrusions during learning of the interpolated list and relearning of the first list has been noted before by McKinney and McGeoch (**10**), Melton and Irwin (**12**), and by Thune and Underwood (**15**), but passed over without theoretical comment. Yet it is a fact of considerable importance in the argument for the two-factor theory of retroactive inhibition as it has been developed by Melton and associates (**12, 13**).

Thune and Underwood (**15**) have made a very important contribution to the understanding of the conditions under which intrusions appear by demonstrating that the intruding response must have a moderate advantage in associative strength over the one it replaces. If it is very much stronger the *S* may be able to recognize it as wrong and reject it before it becomes overt. If it is equal in strength, there is blocking and no overt response; if weaker, it does not intrude at all. Their conclusion, which seems amply justified by their data (**15**, p. 192) corrects an earlier hypothesis made by Melton and Irwin (**12**, p. 196) to the effect that most overt intrusions occur when the two competing response tendencies are of equal strength.

How does the new hypothesis account for the low number of intrusions in interpolated learning? Theoretically one would expect the conditions for overt intrusions to be maximal early in interpolated learning, since the originally learned responses have about the 'right' advantage in strength over the new ones being formed. Yet there are very few such inter-list intrusions. Melton and Irwin found only

around four per condition on the second IL trial, five on the third and three on the fourth, after five trials on the original list (**12**, p. 193). Yet under similar conditions, five OL trials and five IL trials, they found 28 inter-list intrusions on the first recall trial alone (**12**, p. 191). Why are there so few IL intrusions when the conditions are optimal for their appearance according to Thune and Underwood's principle? If the principle is to be accepted, it must be argued that the conditions are not optimal, that actually five original learning trials are not sufficient to give the OL responses the advantage over the new associations [6] in IL required to produce overt intrusions. If this interpretation is accepted, the question then arises of how the *interpolated* responses ever get the required advantages over the OL associations to produce so many intrusions in recall. In Melton and Irwin's study there are only five interpolated trials, which could give IL no greater advantage over OL in RL than OL has over IL in IL, and yet many more overt intrusions appeared in RL. The only way in which the IL responses *could* get sufficient advantage over the OL responses to cause overt intrusions in recall is *for the OL responses to be weakened during the interpolated learning just as the two-factor theory maintains.*

This reasoning is a little elaborate, but it seems clear that the only way in which the discrepancy between the number of overt inter-list intrusions in IL and RL can be explained, if Thune and Underwood's principle is accepted, is in terms of some two-factor theory which maintains that something happens during interpolated learning which makes the conditions for the production of overt intrusions different at recall [7] from what they are during interpolation.

## Summary

The purpose of this experiment was to explore more fully the determinant of retroactive inhibition usually defined as similarity or generalization between the original and interpolated activities. Thirty *Ss* learned a paired-associates list of the form A–B to the criterion of 9 out of 12 correct responses; of these, 15 learned an interpolated list of form A′–B, and 15 one of the form C–D to the

[6] It could not be argued that the OL responses are too strong to intrude because then the intrusions should increase as IL proceeds, which is not the case.

[7] In the present experiment there is the other possibility that the greater number of intrusions in recall is due to the *direction* of association between the stimulus members of the original and interpolated lists. That is, in IL the stimulus word *Grass* does not evoke *Green* which then evokes the originally learned response. But in RL *Green* may readily evoke *Grass*, which calls up the interpolated response. This explanation would certainly have been accepted for the present results except for the fact that the discrepancy between IL and RL intrusions has been found so generally under conditions which do not allow this explanation (**10**, **12**, **15**).

same criterion. The relation between the stimulus terms A and A′ was that of Kent-Rosanoff stimulus words and their frequently free-associated responses. There was no relation between A and C. Differences in the effect of the two kinds of interpolation was measured in terms of recall scores for A–B and in terms of specific inter-list intrusions. The following conclusions appear justified by the data.

(1) Using stimulus terms in the original and interpolated lists which are frequently free-associated produced reliably more retroactive inhibition on the first two recall trials (but not thereafter) than using unrelated stimulus terms.

(2) Reliably more inter-list intrusions appeared in recall when the stimulus terms were related, and they were concentrated in the first three trials which showed the most retroactive inhibition, a fact which indicates it was the relatedness of the two lists which increased the inhibition.

(3) There were reliably more inter-list intrusions in recall than in interpolated learning when the stimulus terms were related, a difference which is interpreted as supporting the two-factor theory of retroactive inhibition.

The general conclusion was that to define the relation between original and interpolated activities which determines the amount of retroactive inhibition as similarity or as generalization (plain or mediated) is too narrow a conceptualization, since it does not cover such a learned, uni-directional relation between the two activities as was demonstrated to be of importance here.

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# STUDIES IN THE TRANSPOSITION OF LEARNING BY CHILDREN. VI. SIMULTANEOUS VS. SUCCESSIVE PRESENTATION OF THE STIMULI TO BRIGHT AND DULL CHILDREN *

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In an earlier experiment of this series (3) it was shown that radically different results are obtained in the transposition experiment depending upon whether, in the training, the stimuli are presented simultaneously or successively. Under the latter conditions, in the critical trials, the absolute response was prevalent, though under the former conditions the relative response was prevalent. This difference in results cannot easily be interpreted in terms of the theoretical mechanism set forth by Spence (6). The authors have suggested (3) that to interpret these results an additional assumption is required, namely, a 'patternedness' factor. No attempt will be made in this report to integrate mathematically this new factor with the Spence theory. However, a verbal analysis at this stage in our understanding may lead to a more precise formulation subsequently.

In the present experiment, two conditions of successive presentation of stimuli are used along with the usual simultaneous method. One of the successive methods of training, hereafter referred to as the one-response method, consists in showing the two stimuli to the *S*s in quick succession (with about a one sec. interval between), then having the *S*s make a choice between the stimuli just as in the case of simultaneous presentation. In the other successive type of training, the two-response method, the stimuli were presented one at a time and after each a reaction was required. The speed of the trials was adjusted so that about the same amount of time was required for one response in the 'one-response' method as for two responses in the 'two-response' method. It was in this manner that training in the two procedures was equated.

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In training by each of these methods, two generalization effects are generated, one about each stimulus, as called for in the Spence theory. It would seem that if these generalization effects are acquired in separate trials, as in the 'two-response' method, they would be more independent than if they were acquired in the same trials as is particularly the case in the simultaneous method. In the latter case two generalizations have some kind of inter-relatedness. It is this property that we have referred to elsewhere as the 'patternedness factor.' Supposedly this factor should be present to the greatest extent under the condition of simultaneous presentation of stimuli, and least with the two-response successive method.

The children used in this study were taken from two sixth grade groups. One, the dull group, was the regular sixth grade class of a given school; the other, the gifted group,[1] was of especially high intelligence, as measured by IQ. They had been gathered together for an extended research program. There were 50 in the latter group and each was matched for age and sex with a member of the former group. Our *S*s could easily be selected in matched pairs. Although the primary concern in this experiment is not to determine the difference between bright and dull *S*s, observed differences between them may turn out to be very illuminating.

## Procedure

The general method used is the photographic-projector technique for studying discrimination learning in groups of children. It has been described in detail elsewhere (2). The stimuli were photographed on 35 mm. film. These were then projected on a screen before five to ten *S*s at a time. Their choices were registered by requiring them to drop numbered tickets into individual ballot boxes containing two (or three) compartments. The numbers on the tickets were coordinated with the trial number.

The stimuli used in training were squares 337.5 sq. mm. and 759.4 sq. mm. respectively, the former being the positive. In critical trials the stimuli were 150 sq. mm. and 337.5 sq. mm. respectively. The backgrounds upon which these were set were 100 mm. square. The largest of these three stimuli occupied less than 8 percent of the total stimulus patch.

In 'simultaneous' training stimuli were presented in each of two adjacent fields on the screen; the child indicated his choice of right or left by putting the ticket for that trial in the ballot box on the right or left side. The reward or punishment for a choice was the information that the ticket should have been put in a certain box. This information was given by a second lantern slide. This was shown immediately after all *S*s had made their choices. In this case the image on the screen was a replica of the two ballot boxes (three in one condition) with an arrow pointing to the 'correct' box for that trial. This method was quite successful and only a few *S*s made an error after the first few trials.

Preliminary training trials were given with other stimulus materials, a square vs. a triangle. This training for the 'simultaneous' group consisted of 10 trials. In these of course the two stimuli were presented simultaneously and 'information' was given after each trial as described

[1] The late Professor Leta S. Hollingworth of Teachers College, Columbia University, had arranged with the Board of Education to have an especially gifted group of 50 children attend the Speyer School (P.S. 500) from February 1936 to February 1941 for purposes of extensive research. It was with her kind permission and enthusiastic support that the research reported here could be done.

above. The stimuli were shown for about 3½ sec., then after about ½ sec. the information was shown for one sec. Two sec. was allowed between trials. On the first few trials it was necessary to give more time for each trial. The time intervals were regulated by rotating, in front of the projector, a disc in which segments were cut out to give the desired program.

Preliminary training for the two 'successive' groups was longer because the task was somewhat harder for the *S*s to learn. Ten trials were first given just as for the 'simultaneous' group, then 10 trials by their respective successive methods. The 'one-response' successive method consisted in presenting one stimulus for about 1.5 sec., then the other stimulus for the same time, and after a brief pause the 'information.' The *S*s were instructed to refrain from making a choice until they had seen the second stimulus. The positive and negative stimuli were shown first an equal number of times.

In the 'two-response' method the two stimuli were shown separately and a separate response was required each time a stimulus was presented. If the positive stimulus appeared in the right hand square or the left hand square, *S* was to put his ticket in the right hand or left hand ballot box accordingly; if the negative stimulus appeared in either square he was to discard the ticket, that is put it in a third box referred to as the waste-basket.

In this study it was desired to find out the amount and direction of transfer (transposition) at different degrees of practice; accordingly critical trials were given after 10, 40 and 100 trials of training. On the first two of these occasions only two critical trials were given; this small number of trials was used in order to avoid disturbing the training. After the 100th trial four critical trials were given. In case of the 'two-response' method it would seem that just twice as many responses would be necessary to give a corresponding amount of training as with either of the one-response methods. Whether this is strictly true or not, we have proceeded on that basis. The stimuli were presented simultaneously in all critical trials.

## Subjects

As *S*s, 72 sixth grade school children were used. Of these, 36 were taken from the gifted group previously mentioned; 36 children from the regular classes who had been matched with the gifted children were also used. Each of these groups was subdivided into groups of 12 equated for IQ. All six groups were equated for age. Table I shows the relevant data on these groups.

TABLE I

Averages and Standard Deviations for Age and IQ for Each Group of *S*s

| Method of Training | Age in Months | | | | IQ | | | |
|---|---|---|---|---|---|---|---|---|
| | Gifted | | Dull | | Gifted | | Dull | |
| | Ave. | SD | Ave. | SD | Ave. | SD | Ave. | SD |
| Simultaneous | 138.4 | 8.8 | 139.3 | 8.8 | 150.6 | 21.8 | 85.9 | 8.9 |
| Successive One Response | 138.5 | 8.5 | 136.7 | 8.8 | 150.7 | 14.6 | 85.8 | 8.6 |
| Successive Two Responses | 138.0 | 8.3 | 136.3 | 8.3 | 150.1 | 18.3 | 85.8 | 6.2 |

## Results

Before considering the principal results, it may be pointed out that the number of errors made in training was very small (see Table II) for both groups of *S*s, the gifted and the dull. As would be expected the former made fewer errors than the latter. As between methods, the greatest number of errors were made in the 'successive two-response' method. The number of errors is sufficiently low that the results in the critical trials may be compared without par-

TABLE II

MEDIAN AND Q OF THE PERCENT OF ERRORS MADE IN THE TRAINING BY EACH GROUP

| Method of Training | Gifted Subjects | | Dull Subjects | |
|---|---|---|---|---|
| | Mdn. | Q | Mdn. | Q |
| Simultaneous | 2.0 | 1.75 | 3.5 | 2.75 |
| Successive One Response | 1.5 | 2.25 | 3.5 | 4.5 |
| Successive Two Responses | 1.75 | 1.25 | 5.0 | 2.25 |

ticular qualification with respect to goodness of training. The learning curves showed the characteristic slope, the greater number of errors occurring in the early part of the curve.

The primary results are shown in Tables III, IV, and V. It seemed necessary to show the data in some detail so that the consistency of the performance of the individual *S*s could be observed as well as the trend of the group results. This consideration is particularly important in the case of the groups using the successive two-response method.

With respect to the 'simultaneous' group, the results show almost complete relative choice, even at different stages of training. The difference between the gifted and the dull groups is negligible. As

TABLE III

RESPONSES (R = RELATIVE, A = ABSOLUTE, X = NO RESPONSE) MADE BY EACH *S* IN EACH CRITICAL TRIAL WHO WAS TRAINED BY THE 'SIMULTANEOUS' METHOD

| Gifted Subjects | | | | | | | | | Dull Subjects | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Subject No. | After 10 Trials of Training | | After 40 Trials of Training | | After 100 Trials of Training | | | | Subject No. | After 10 Trials of Training | | After 40 Trials of Training | | After 100 Trials of Training | | | |
| | C.T. | | C.T. | | C.T. | | | | | C.T. | | C.T. | | C.T. | | | |
| | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 |
| 1 | R | R | R | R | R | R | R | R | 1 | R | R | R | R | R | R | R | R |
| 2 | R | R | A | R | R | R | R | R | 2 | R | R | R | R | R | R | R | R |
| 3 | R | R | R | R | R | R | R | R | 3 | R | R | R | R | R | R | R | R |
| 4 | R | R | R | R | R | R | R | R | 4 | R | R | R | R | R | R | R | R |
| 5 | R | R | R | R | R | R | R | R | 5 | R | R | R | R | A | R | R | R |
| 6 | R | R | R | R | R | R | R | R | 6 | A | A | R | R | R | R | R | R |
| 7 | R | R | R | R | R | R | R | R | 7 | R | R | R | R | R | R | R | R |
| 8 | A | A | R | R | R | R | R | R | 8 | R | R | R | R | A | R | R | R |
| 9 | R | R | R | R | R | R | R | R | 9 | R | R | R | R | R | R | R | R |
| 10 | R | R | R | R | R | R | R | R | 10 | R | R | R | R | R | R | R | R |
| 11 | R | R | R | R | R | R | R | R | 11 | R | R | R | R | R | R | R | R |
| 12 | A | A | R | R | R | R | R | R | 12 | R | R | R | R | R | R | R | R |
| Total 'R' | 10 | 10 | 11 | 12 | 12 | 12 | 12 | 12 | | 11 | 11 | 12 | 12 | 10 | 12 | 12 | 12 |
| Total 'A' | 2 | 2 | 1 | 0 | 0 | 0 | 0 | 0 | | 1 | 1 | 0 | 0 | 2 | 0 | 0 | 0 |
| Total 'X' | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |

TABLE IV

RESPONSES (R = RELATIVE, A = ABSOLUTE, X = NO RESPONSE) MADE BY EACH *S* IN EACH CRITICAL TRIAL WHO WAS TRAINED BY THE 'SUCCESSIVE ONE-RESPONSE' METHOD

| Gifted Subjects | | | | | | | | | Dull Subjects | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Subject No. | After 10 Trials of Training | | After 40 Trials of Training | | After 100 Trials of Training | | | | Subject No. | After 10 Trials of Training | | After 40 Trials of Training | | After 100 Trials of Training | | | |
| | C.T. | | C.T. | | C.T. | | | | | C.T. | | C.T. | | C.T. | | | |
| | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 |
| 1 | R | R | R | R | R | R | R | R | 1 | A | A | A | A | A | A | A | A |
| 2 | R | R | R | R | R | R | R | R | 2 | R | R | R | R | R | R | R | R |
| 3 | A | A | A | A | R | R | R | R | 3 | R | R | R | R | R | R | R | A |
| 4 | R | R | R | R | R | R | R | R | 4 | A | R | R | R | R | R | R | R |
| 5 | R | R | R | R | R | R | R | R | 5 | A | A | R | R | R | R | R | R |
| 6 | R | R | R | R | R | R | R | R | 6 | R | R | R | R | R | R | R | R |
| 7 | A | A | R | R | R | R | R | R | 7 | A | A | R | A | R | R | R | R |
| 8 | R | R | R | R | R | R | R | R | 8 | R | R | R | R | R | R | R | R |
| 9 | A | A | R | R | R | R | R | R | 9 | R | R | R | R | R | R | R | R |
| 10 | R | R | R | R | R | R | R | R | 10 | R | R | R | R | R | R | R | R |
| 11 | A | A | R | R | R | R | R | R | 11 | A | A | R | R | R | R | R | R |
| 12 | R | R | R | R | R | R | R | R | 12 | A | A | R | R | R | R | R | R |
| Total 'R' | 8 | 8 | 11 | 11 | 12 | 12 | 12 | 12 | | 6 | 7 | 11 | 10 | 11 | 11 | 11 | 10 |
| Total 'A' | 4 | 4 | 1 | 1 | 0 | 0 | 0 | 0 | | 6 | 5 | 1 | 2 | 1 | 1 | 1 | 2 |
| Total 'X' | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |

TABLE V

RESPONSES (R = RELATIVE, A = ABSOLUTE, X = NO RESPONSE) MADE BY EACH *S* IN EACH CRITICAL TRIAL WHO WAS TRAINED BY THE 'SUCCESSIVE TWO-RESPONSE' METHOD

| Gifted Subjects | | | | | | | | | Dull Subjects | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Subject No. | After 20 Trials of Training | | After 80 Trials of Training | | After 200 Trials of Training | | | | Subject No. | After 20 Trials of Training | | After 80 Trials of Training | | After 200 Trials of Training | | | |
| | C.T. | | C.T. | | C.T. | | | | | C.T. | | C.T. | | C.T. | | | |
| | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 |
| 1 | R | R | R | R | R | R | R | R | 1 | R | R | A | A | A | A | A | A |
| 2 | A | A | A | A | A | A | A | A | 2 | R | X | X | R | R | R | R | R |
| 3 | R | A | A | R | R | R | R | R | 3 | R | X | R | X | A | A | X | R |
| 4 | R | R | R | R | R | R | R | R | 4 | A | A | A | A | A | A | A | A |
| 5 | R | R | A | A | A | A | A | A | 5 | A | A | A | A | A | A | A | A |
| 6 | R | R | R | R | R | R | R | R | 6 | R | X | R | R | R | R | R | R |
| 7 | X | X | A | A | A | A | A | A | 7 | X | A | X | X | X | X | X | X |
| 8 | X | X | X | X | X | X | X | X | 8 | R | A | A | A | A | A | A | A |
| 9 | R | R | A | A | A | A | A | A | 9 | R | R | R | R | R | R | R | R |
| 10 | R | R | R | A | A | A | A | A | 10 | R | R | R | R | X | R | R | R |
| 11 | R | A | A | A | A | A | A | A | 11 | A | X | R | X | R | R | R | R |
| 12 | R | R | A | R | A | A | A | A | 12 | R | R | R | R | R | R | R | R |
| Total 'R' | 9 | 7 | 4 | 6 | 4 | 4 | 4 | 4 | | 8 | 4 | 6 | 5 | 5 | 6 | 6 | 7 |
| Total 'A' | 1 | 3 | 7 | 5 | 7 | 7 | 7 | 7 | | 3 | 4 | 4 | 4 | 5 | 5 | 4 | 4 |
| Total 'X' | 2 | 2 | 1 | 1 | 1 | 1 | 1 | 1 | | 1 | 4 | 2 | 3 | 2 | 1 | 2 | 1 |

stated in previous studies (4, 5) the few absolute choices made after 10 trials of training were due to the fact that training had not gone far enough to induce stable choice. Stable relative choice appears only at the second and third degrees of training; a transition to absolute would begin only after considerably more training. The results for the group using the successive one-response method show very much the same trend, that is, somewhat unstable choice preceded stable relative choice. The reason for the somewhat greater instability in the first critical trials with this method as compared with the simultaneous method may have been the change to simultaneous presentation in the critical trials. However, all groups had had some practice with this method in preliminary training. The most noticeable difference between the gifted and dull groups appears in the first and second critical trials. It is important to notice that the individual *Ss* responded consistently. The absolute choices made are not randomly distributed but are in line, as individuals, with trends of choice previously stated. For example, one individual making absolute choices in critical Trials 3 and 4 is the one who also made absolute choices in critical Trials 1 and 2. The same is generally true for the dull group. There was only one *S* who varied from consistent choice in that group. It may also be pointed out that the one *S* who made a stereotyped 'A' choice all through the critical trials, had the lowest IQ (74) in that group. As with the simultaneous group, the trend here indicated that the transition away from relative choice to a stable absolute choice would require at least another hundred trials by training.

The general trend with the group having used the successive two-response method is not toward relative choice but toward absolute choice. These results also seem to be in line with the sequence of choices found in a previous experiment. These results fall in line with the 'second transition,' i.e., from the stable relative to the absolute choice, which normally occurs only after prolonged training. To explain these results in such terms it is necessary to assume that the stage of practice during which relative choice would occur is very short and that learning is very rapid with this method. Perhaps there is no stage of training at which all *Ss* would make all relative choices. This method then favors the absolute choice. However, the tendency to make relative choice is clear enough to indicate that the three stages of choice are followed here as in the usual transposition experiment.

The difference between the gifted and the dull groups is more marked here than in either of the other methods. The trends discussed above are most clear with the gifted group. Six of the 12 *Ss* made changes in line with what was described as the trend; four made

no change and only one made a change contrary to the trend. It may also be noted that the six making choices in line with the trend had the high IQ's of the gifted group, their IQ's being 189, 175, 170, 156, 147, 140 respectively. In the dull group two *S*s fell in line with the trend and two others showed a slight tendency in this direction, three made choices contrary to the trend, four made no changes and one did not respond at all. There was no correlation between IQ and trend of choice.

In the previous study by the writers (**3**) the traditional simultaneous training was compared with the two-response successive method of training. The latter method produced a preponderance of absolute choices and the former all relative choices. It could not be determined on the basis of those results whether the results were due to successive presentation of stimuli, per se, or if they were due to the fact that that particular successive method required a different 'set' (task) for the *S*. The results presented above indicate that it was not successiveness, per se, for the successive one-response method yields approximately the same results as the simultaneous method. The set or task of the *S* was the same for these two methods. In the simultaneous method there was no time between the two stimuli; in the one-response successive method it was about one sec. It would seem that approximately the same results would occur if this time difference were increased several sec. (even five) providing the 'task' remained the same.

In the two-responses method the time interval between the two stimuli (presented in two separate trials) was approximately five sec. but the task was very different, a distinct and separate response being made to each stimulus. The results, as we have seen, are very different for this method. This difference seems clearly to be due to the 'task' rather than to the fact of successiveness per se.

Again the question arises as to how Spence's theory applies to this general problem. Since he assumes two generalization effects, of the type discussed by Pavlov and others, he must mean (implicitly) two separately acquired generalizations. Pavlov speaks of no other kind. Since this must be the case Spence's theory may be expected to apply better to transposition results when the training has been by the two-response successive method.

Since Spence's theory as yet has no way of accounting for the discrepancy between the two sets of results shown here, we again point out that his theory must be supplemented with a patternedness factor to account adequately for traditional transposition results.

The previous finding (**4, 5**) that transposition results pass through three stages, as amount of training is increased, is in no way altered by the present study. However, it is clear that these stages are

passed through much more quickly if training is by the two-response successive method.

Apparently, in the two-response method, in order to make correct choices in a series of trials the *S* must retain a fairly good absolute impression of previous stimuli, and to do this he must pay much closer attention than in the case of the simultaneous method. The presence of this closer attention with this method indicates why learning is much more rapid, and why the three stages of transposition learning are passed through so quickly. In our results the optimum degree of practice for relative choice was apparently less than 10 trials, whereas with the simultaneous method it is beyond 100 trials.

The fact that so much attention to the stimuli is required with the two-response method accounts in part at least for the poor performance of the low IQ group.

The difference between the gifted and the dull groups was slight in the two methods which were easily learned, but was considerable in the last method which was rather difficult. Such a trend is quite in line with the findings of Hollingworth (1) that gifted children reveal their superiority much more in complex materials. In this study no qualitative difference between the two groups came to light.

## Summary

The influence of three different methods of training upon the type of choice made with transposed stimuli was studied. The stimuli were small squares of different areas. Gifted children were compared with dull children.

The traditional method of training was used, that is, the stimuli were presented simultaneously. The second method consisted in the successive presentation of stimuli, one following the other after one second. In this training the *S*s withheld choice until the second stimulus appeared. In the third method the stimuli were presented successively about five sec. apart but here a response (right or wrong) was required after each.

Critical trials were given after 10, 40, and 100 trials of training.

In the simultaneous and successive one-response methods, the results were similar, the relative choice was favored after 10 trials, was greater after 40, and practically universal after 100 trials. With the successive two-response method, the absolute response was favored at 10 trials and the percent of absolute choices increased as training was continued.

The difference between the two-response successive method and the other methods of training is interpreted as being due to the set or task of the *S* and not to the fact that the stimuli were presented successively.

The gifted group differed but slightly from the dull in the case of the simultaneous and successive one-response methods; in the last, however, they differed markedly. The dull group, as a group, did not respond consistently to the critical trial situation.

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# AN ATTEMPT TO MEASURE 'PERSISTENCE' IN ITS RELATIONSHIP TO SCHOLASTIC ACHIEVEMENT

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## Introduction

Studies of persistence have been of two chief types: those concerned with determination of whether persistence is a general or a specific personality trait, and those seeking to determine the relationship of persistence to success in academic work. In both, two weaknesses have been apparent. The first has been a failure to devise a definition of persistence that would not only clarify interpretation of a given experiment but would also permit reasonable comparison with the findings of other workers (**14**). The second weakness has been a failure to limit the experimental approach to persistence by what seem to be logical demands upon a design whose purpose is to measure that variable. Thus, some workers have proposed measures of resistance to pain and to fatigue as measures of persistence (**6**, **10**, **21**). The present study has sought to overcome both of these weaknesses.

In the first place, persistence is defined as a personality trait which is evidenced in the individual as a tendency to continue activity, once initiated, along a given line, in spite of increasing frustration, until the original goal of the activity is achieved to a degree compatible with certain personal or social criteria of achievement or until his resistance to frustration is exhausted. Secondly, it is held that persistence so defined can only be measured in terms of the individual's reaction in a situation to which he brings relevant motivation, in which he is frustrated, and for which he has either an intrinsic or extrinsic criterion of performance.

## Subjects

The *S*s for the study were 11 male and 14 female undergraduates, all dormitory residents at the University of Minnesota. On the basis of discrepancies between their A.C.E. percentile ranks and those of their academic indices for the first two quarters of the school year, they were selected as either under-achievers or over-achievers. The minimum discrepancy allowed was 20 percentile points. The average discrepancy was 39 points for the 6 male over-achievers, 34 points for the 5 male under-achievers, 37 for the 8 female over-achievers, and 34 for the 6 female under-achievers.

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## Apparatus

The apparatus used was an elevated finger maze consisting of a complex pattern of wires set into a 2-foot square, 5 ply board. This maze had *no* solution although subjects were told it did have. The maze was clamped before *S* at one end of a table and *E* sat at the other end of the table, equipped with a Kodak timer, notebook, and pencil. By means of a cardboard cover over the maze and a pair of taped goggles used with sterile tissue to form a blindfold, *S* was prevented from seeing the maze.

## Procedure

The *S*s were informed that the test was one of their ability to learn and that it was a very difficult test. They were encouraged to do their best and told that if unsuccessful in finding the end of the maze, they could terminate the test by speaking to *E*.

By means of the Kodak timer, *E* obtained a measure of *S*'s persistence on the maze. Also, *E* kept a detailed written record of all significant behavior of *S*, e.g., talking, laughing, fidgeting in the chair, etc.

## Results

Table I presents the basic data derived from the experiment. The persistence score for an *S* was the total time, in minutes, spent

TABLE I

Means and Standard Deviations for Each of the Four Variables for the Various Sub-groups

| Group* | N | Persistence | | Restlessness | | Verbalization | | Questioning | |
|---|---|---|---|---|---|---|---|---|---|
| | | $\bar{x}$ | s | $\bar{x}$ | s | $\bar{x}$ | s | $\bar{x}$ | s |
| MO | 6 | 60.5 | 16.6 | .63 | .37 | 9.81 | 7.28 | .69 | .53 |
| MU | 5 | 45.6 | 15.4 | 1.68 | 1.73 | 6.49 | 5.32 | .32 | .37 |
| FO | 8 | 40.3 | 21.8 | .78 | .90 | 3.46 | 3.90 | .23 | .37 |
| FU | 6 | 33.3 | 13.6 | .86 | .66 | 7.20 | 8.08 | .60 | .83 |
| M | 11 | 53.7 | 17.8 | 1.11 | 1.31 | 8.30 | 6.67 | .52 | .50 |
| F | 14 | 37.2 | 19.3 | .81 | .77 | 5.06 | 6.33 | .39 | .64 |
| O | 14 | 48.9 | 22.3 | .71 | .73 | 6.18 | 6.43 | .42 | .50 |
| U | 11 | 38.8 | 15.9 | 1.23 | 1.33 | 6.89 | 6.99 | .47 | .67 |

* Symbols: MO = all male over-achievers; MU = all male under-achievers; FO = all female over-achievers; FU = all female under-achievers; M = all males; F = all females; O = all over-achievers; and U = all under-achievers.

on the maze. The three indices reported are expressed, per *S*, as the average number of occurrences of that behavior per five-min. interval on the maze. For example, an *S* who worked on the maze 40 min. and spoke 32 words would have a verbalization index of 4.00. In obtaining the index of restlessness, such things as fidgeting in the chair, changing position of body, sighing, etc., were counted. The question index utilized the number of questions asked and not the number of words in these questions.

TABLE II

VALUES OF *t* AND P FOR THE DIFFERENCES BETWEEN THE SEVERAL SUB-GROUPS IN PERSISTENCE SCORES AND INDICES OF RESTLESSNESS, VERBALIZATION, AND QUESTIONING *

| Comparison | Persistence | | Restlessness | | Verbalization | | Questioning | |
|---|---|---|---|---|---|---|---|---|
| | *t* | P | *t* | P | *t* | P | *t* | P |
| MO–MU | 1.38 | .195 | 1.31* | .226 | .77 | .444 | 1.19 | .090 |
| MO–FO | 3.24 | .008 | .36* | >.70 | 1.94 | .082 | 2.03 | .069 |
| MO–FU | 2.53 | .031 | .68* | >.50 | .54 | .60 | .19 | >.80 |
| FO–MU | .44 | >.60 | 1.13* | .295 | 1.19* | .255 | .55* | >.60 |
| FO–FU | .69 | .56 | .17* | >.80 | 1.06* | .293 | 2.66* | .019 |
| MU–FU | 1.28 | .226 | 2.19 | .055 | .15* | >.80 | 1.34* | .226 |
| M–F | 2.12 | .047 | .69 | .491 | 1.19 | .242 | .54 | >.60 |
| O–U | 1.42 | .175 | 1.19* | .242 | .25 | >.70 | .20 | >.80 |

* The differences are in favor of the group listed first, e.g., MO's have higher persistence average than MU's, except when the *t*-value carries an asterisk, in which case the second group has the larger average. Those *t*-values considered significant (P = .05 or less) are underlined.

Table II presents the results of tests of significance applied, with regard to all four variables, to comparisons of all possible combinations of the sub-groups used in the study. The consistent trend in mean persistence scores from MO [1] through MU and FO to FU, and the significance differences (P = .05 or less) between MO–FO, MO–FU, and M–F seem to indicate a real sex difference in persistence, at least insofar as the sample is concerned. Since selection of the *Ss* within their respective sub-groups was random, it is reasonable to expect that the sex differences obtain in the population from which the sample was taken.

With regard to restlessness, only one comparison, MU–FU, shows a difference approaching statistical significance (P = .055). However, in the five comparisons in which only one of the sub-groups consists of under-achievers (MO–MU, MO–FU, FO–MU, FO–FU, O–U), the group of under-achievers shows greater restlessness in each case. Thus, there is a consistent tendency for the under-achievers to be more restless than the over-achievers.

As regards both verbalization and questioning, of the five comparisons involving unlike-sex sub-groups (MO–FO, MO–FU, FO–MU, MU–FU, M–F), the male groups were found to have been more verbal and to have asked more questions in four of them. In the FU–MU comparison, the female under-achievers were found to have been more verbal and to have asked more questions than the male under-achievers.

[1] See bottom of Table I for meaning of symbols.

The performance of the MO's in each of the four variables measured is noteworthy. They are consistent in their superiority or inferiority to the other groups in each of the measures. Thus, we find the MO's to be consistently more persistent, more verbal, more questioning, and less restless than the other three groups with which they are compared.

Rogers (**12**, **13**), in using a group test to determine ratings on 'perseveration' of public school pupils, analyzed his results in terms of disparities between intelligence and achievement. Speaking of a *positive* disparity when an individual's scholastic achievement surpassed his intelligence, both expressed as standard scores, and of a *negative* disparity when the reverse held, Rogers found that individuals with high perseveration scores who were above the average of their class in intelligence showed a tendency toward negative disparities while those with high perseveration scores who were below the class average in intelligence showed a tendency toward positive disparities. To check Rogers' findings, the writer studied the 10 *Ss* having the highest persistence scores. Of those below the 50th centile of the A.C.E., three in number, two showed positive disparities and one a negative. Of those above the 50th centile, five in number, three showed positive and two negative disparities. Due to the small number of cases, it is not safe to generalize from these results, but they do not appear to substantiate Rogers' findings.

Ryans (**16**), in a study utilizing a battery of three items to measure persistence, assumed that where there was a disparity between measured intelligence and school achievement, with school achievement higher, the greater the disparity the more persistent the individual. To test this assumption in the present study, rank-order correlation coefficients were obtained between persistence scores and amount of disparity between A.C.E. percentile ranks and percentile ranks of honor-point indices. The correlation between the two variables was +.36 for all *Ss*, but only +.05 for all over-achievers. Interestingly, the two variables correlate +.20 with the MO's and −.34 with the FO's. Ryans' assumption that the greater the over-achievement the more persistent the individual is not corroborated by the tentative findings of the present study. A further study with better control in selection of *Ss* would be necessary to determine if the discovered relationship of persistence to achievement in the female over-achievers is due to inadequate sampling, the result of the particular measure of persistence used, or the expression of the actual relationship of persistence to success in the academic fields predominating in the girls' programs as contrasted with those of the boys.

As the findings of this experiment are reviewed, it is clear that the superiority of this approach to the measurement of persistence

lies in the opportunity provided for the close observation of individual differences not only in persistence as such but in the type of behavior characterizing persistent activity.

## Summary and Conclusions

Using an insoluble, elevated, finger maze to obtain measures of persistence (total time spent on the maze) for 14 over-achievers and 11 under-achievers selected on the basis of disparities between A.C.E. percentile rank and percentile rank for academic index, the following tentative conclusions are indicated:

1. There is a decided and statistically significant sex difference in persistence which favors the males of the sample.

2. While persistence is correlated to a slight positive degree with over-achievement in the males, it is correlated negatively to about the same degree with over-achievement in the females.

3. There is a tendency for the under-achievers to be more restless than the over-achievers in a situation demanding persistence. Furthermore, there is a tendency for greater restlessness to be associated with less persistence, and likewise, a tendency for less persistence to be associated with under-achievement.

4. The males tend to be more verbal in general and also tend to ask more questions than the females in a situation calling for persistent behavior in the presence of a single male.

5. The male over-achievers are consistently more persistent, more verbal, more questioning, and less restless than the male under-achievers, or the female over-achievers, or under-achievers.

6. Neither Ryans' assumption that degree of over-achievement is positively related to persistence, nor Rogers' finding that 'high perseverators' below the average in intelligence show positive disparities while those above the average show negative disparities is substantiated by the present study.

7. The use of a non-soluble elevated finger maze to obtain measures of persistence is particularly valuable because of the opportunity it affords for observation of other significant behavior accompanying persistent activity.

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